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THE DEVELOPMENT OF A METHOD TO LOAD JP4 ABOARD TANKERS WHICH  
PROTECTS ITS ANTI-ICING PROPERTIES, ELIMINATES TANK DRYING, AND  
RESULTS IN SIGNIFICANT SAVINGS IN TIME AND MONEY

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FREDERICK WILLIAM MARCH

1968

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THE DEVELOPMENT OF A METHOD TO LOAD JP4 ABOARD  
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IN TIME AND MONEY

by 15

Frederick William March  
B.S., United States Naval Academy, 1959

Submitted to the Department of Chem-  
ical and Petroleum Engineering and  
the Faculty of the Graduate School  
of the University of Kansas in par-  
tial fulfillment of the requirements  
for the degree of Master of Science.



## ABSTRACT

The jet fuel currently used by the United States Air Force requires an anti-icing additive because of the long range, high altitude aircraft now in use. When transporting this jet fuel by tanker, all water must be removed from the vessel's tanks since the additive is highly soluble in water. In his three years experience as a petroleum inspector, the author has observed that tankers lifting JP4 are delayed approximately 12 hours per cargo at a cost of approximately \$2,000 per cargo because of this tank drying requirement. Upon assignment to the University of Kansas in the Navy sponsored Petroleum Management Post Graduate Program, the author undertook, as his thesis project, the development of a less costly method of loading JP4, basing his study primarily upon laboratory tests but realizing that actual field tests would be required for conclusive results.

Laboratory tests conducted indicate that the icing inhibitor concentration in the fuel may be maintained within the military specification limits of 0.10-0.15 per cent as long as a sufficient quantity of inhibitor is injected to satisfy the equilibrium concentration requirement of the water remaining aboard the vessel after normal deballasting. In most cases, no more icing inhibitor is required than is called for by the maximum military specification limit. Tests conducted at the University of Kansas and the author's own



experience in loading tankers indicate that extensive savings in time and money may be realized by using the proposed method. Using the new method could result in a savings of approximately 12 hours turn-a-round time per cargo lifted, a savings which is of immediate significance to the military. By using the new method, a savings of approximately \$2,000 per cargo in drying time could also be realized, a savings of immediate significance to tanker operators. On a yearly basis, the author estimates that more than 4,000 hours in tanker turn-a-round could be saved as well as \$700,000 in drying costs. The author recommends, therefore, that field tests be conducted using actual vessels and that if these tests are successful the new method be adopted as soon as possible.



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F. W. M.



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## CHAPTER I ·

### INTRODUCTION

#### Icing Problems in the Jet Age

During the past 10 years the turbo-prop and turbo-jet aircraft have become dominant in military air defense. The development of the jet aircraft required new construction and new design techniques. Many features of conventional piston engine planes were adaptable to new jet aircraft and were incorporated in their construction. One such feature was the application of heat at critical points in the fuel system where moisture caused icing problems. The fuel heater at the filter in the jet aircraft performed the same function as the carburetor heater in the piston engine plane.

The jet fuel, grade JP4, used by the United States Air Force is a lighter and more volatile product than that used by most commercial airlines. Specification requirements limit the gravity to between 45-57° A.P.I. The fuel itself must have a freezing point of -72°F or below. JP4 normally contains 70-100 parts per million of water in solution.<sup>1</sup> This small quantity of water causes the basic problem since at high altitude or low ground temperatures, the water present in the fuel condenses and deposits of ice are formed on fuel system parts.

By 1958 it became apparent that the icing problem was not solved. The newer, high altitude, long range jets exper-



experienced a variety of icing problems including malfunction tendencies of fuel controls, ice plugging of fuel filters, and freeze-up of fuel boost and transfer pumps. The most serious problem of all was engine flame out. Since fuel heaters in operational aircraft were not providing adequate icing protection, and aircraft designers could not, in many cases, incorporate larger fuel heaters into future aircraft, a new approach to the icing problem was taken.

In June of 1958, the United States Air Force invited chemical and petroleum companies to participate in a search for a fuel additive which would eliminate the icing problem. By 1962 an icing inhibitor developed by the Phillips Petroleum Company, PFA 55MB, had been thoroughly tested and was accepted by the Air Force. In September of 1962 the JP4 specification, MIL-T-5624, was formally modified requiring the addition of icing inhibitor in concentrations of 0.10-0.15 per cent by volume. The present JP4 specification, MIL-T-5624G, is included as Appendix A. The icing inhibitor in use today is a modified composition of the original inhibitor developed and consists of 99.6 per cent ethylene glycol monomethyl ether and 0.4 per cent glycerol by weight. MIL-27686D is the military specification now in use and is included as Appendix B.

#### The JP4 Transportation Problem

One of the greatest problems which originated with the requirement for the additive arose in the transportation





field. The additive is highly soluble in water and migrates from the fuel into any water with which it comes into contact. When JP4 is shipped by vessel, water contact is difficult to prevent. Unfortunately, the additive has no preference and acts on sea water the same as fresh water. Due to the great demand for JP4, the usual shipment is by full tanker lot. Tankers scheduled for JP4 lifts proceed from their previous discharge port to loading port without cargo, but must necessarily carry sea water ballast for stability. In most cases ballast must be distributed equally throughout the ship to prevent excessive stress on the longitudinal members. Because of absorption of the additive by water, all free sea water is removed from a vessel's tanks prior to loading JP4. The water removal operation consists of sending men down into all cargo tanks with buckets and mops or eductors to remove any free water which remains after the vessel has pumped out the sea water ballast. This operation is very costly to the carrier. Not only is the shipping company paying normal wages to the entire crew during the drying operation, but also a premium pay rate to the men who are working in the tanks.

The drying operation creates problems for the refiner. The time required to dry a vessel's tanks can not be predicted with a great degree of accuracy. While a vessel is drying tanks at the pier, the refiner must schedule pier space for waiting vessels and expected arrivals. One JP4 ship in port



can easily cause costly scheduling delays and inefficient use of loading lines.

The cargo purchaser is also faced with problems when tank drying is required. He is indirectly paying for the drying time in higher freight rates. In some cases he must either wait days past his expected delivery date to receive the cargo or divert a cargo in transit to where it is most needed. Cargo diversions compound his scheduling problems.

### Purpose of Thesis

While working as a U.S. Navy Petroleum Inspector in the Caribbean area, the author became aware of the difficulties encountered in loading JP4 and considered that possibly the difficulties could be reduced if a better method could be developed for solving the problem presented by the small amounts of water remaining in a vessel's tanks after deballasting. A better understanding of the mechanism of icing inhibition could also be of great value to military personnel in operating fuel billets. The purposes of this thesis therefore are to:

1. Provide a source of information to Military Petroleum Offices at the working level which will promote a better understanding of the process of distribution of the anti-icing additive between fuel and water.
2. Investigate the economic feasibility of eliminating the drying of a vessel's tanks when lifting JP4 by increasing the anti-icing content of the fuel by the



amount which will be absorbed in any water remaining after normal deballasting.

3. Provide a time-saving method to load JP4 in an emergency, regardless of cost.



## CHAPTER II

### TANKER OPERATIONS

#### Introduction

In 1966, approximately 153,837,000 barrels of jet fuel, grade JP4, were purchased by the United States Air Force. Of this amount, approximately 48,300,000 barrels were transported by tanker to their destination.<sup>2</sup> Tankers which carry military products can be divided into two groups: those in black service and those in clean service. The black service tankers carry products such as Bunker "C" and Navy Special Fuel Oil while the clean service tankers carry diesel fuels, motor gasoline, kerosine, jet fuel, and aviation gasoline. Jet fuel, being in the clean product category, is carried exclusively aboard clean service tankers, and it is this type of tanker which will be discussed. It should be noted that there is no apparent physical difference between the tankers in clean and in black service. The clean service tankers discussed are not to be confused with Fleet Oilers. The ships under discussion are Navy owned, civilian manned tankers and civilian owned and operated ships chartered by the Military Sea Transportation Service.

There are so many classes of tankers in use today that it would be impossible to discuss the differences of each. The same basic procedures in preparation for loading are required by every ship. The smallest tanker still in wide use





by the military has been selected as the basis for study since its size contributes to providing the most severe test case. That is to say, if the proposal presented has merit using a small tanker, it is expected that a larger tanker will produce even better results. The type tanker selected was the 16,000 dead weight ton ship designated T2. The Military Sea Transportation Service has approximately 16 T2's in clean service operation. A T2 normally carries from 135,000 to 138,000 barrels of JP4, depending on the gravity of the product. The ship has 26 cargo tanks, 9 wing tanks on each side with 8 center tanks between. Figure 1 is a top view of a T2 showing the cargo tank arrangement.

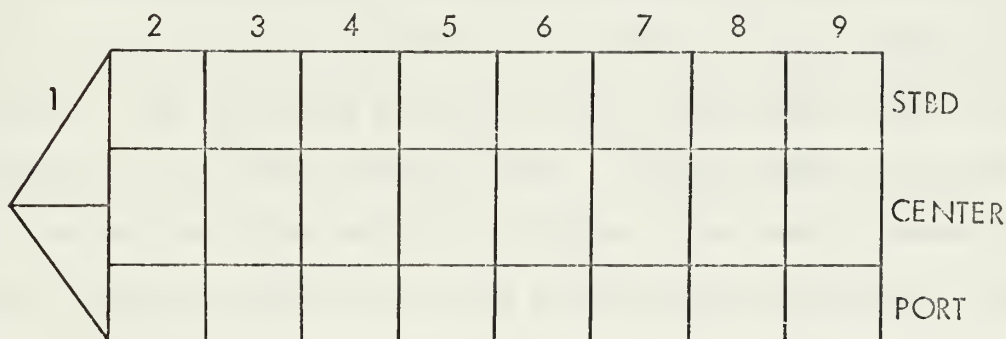


Figure 1 - T2 Cargo Tank Arrangement

### Tank Cleaning

After discharging cargo, a tanker must take on sea water ballast prior to leaving the pier. This is necessary for stability and steering control of the ship. The ship's sea suctions, located in the pumproom, are opened and sea



water passes from the pump room through the below deck main lines and into the cargo tanks.

If a product other than the one just carried is to be lifted next, a thorough cleaning of the vessel's tanks is mandatory. In the event the same product is to be carried again, normal procedure would require no tank cleaning. JP4 is the exception to this procedure. In order properly to inspect a vessel which is to load JP4, it is necessary for an inspector actually to enter the tanks in order to determine that there is no free water. The tanks must be gas free, a condition which can only be accomplished by a thorough cleaning.

Tank cleaning is a costly operation. It involves the removal of the previous product from cargo tanks, pipelines, and pumps. The cleaning process takes place while the ship is enroute to its next loading port. Cargo tanks are washed with a mechanical type washing machine. The most common type machines used are the Pyrate and Butterworth machines. High pressure streams of hot or cold water are discharged from the washing machine nozzles to clean the tanks. Figure 2 shows a typical tank washing machine.



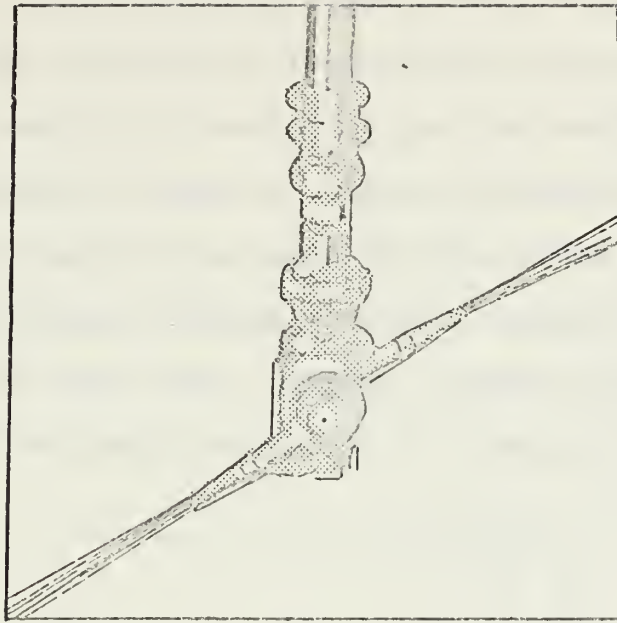


Figure 2 - Tank Washing Machine<sup>3</sup>

Sea water is passed through the fire and tank washing pumps where pressure is boosted. If hot water is desired, heat is then applied enroute to the tank washing machine. The machine is suspended from the top of the tank and slowly lowered to various levels at specific time intervals depending on the degree of cleanliness desired. As the water passes through the nozzles, they are rotated vertically and at the same time a circular horizontal motion occurs which insures that the stream contacts all visible surface areas inside the tank.

The application of heat and additional pump power during tank cleaning increases fuel consumption by the vessel and in many cases reduces the vessel's speed.

A tanker lifting a clean product other than jet fuel proceeds to the dock and pumps out the sea water ballast



from all tanks. Each tank has a main suction valve through which any product entering or leaving the tank must pass. Each tank also contains a stripping suction smaller than the main suction, which is used to pump out product which remains after suction is lost at the main suction valve. The stripping suction is located behind the main suction against the after bulkhead of each tank. Figure 3 shows the locations of the main and stripping suctions in a cargo tank.

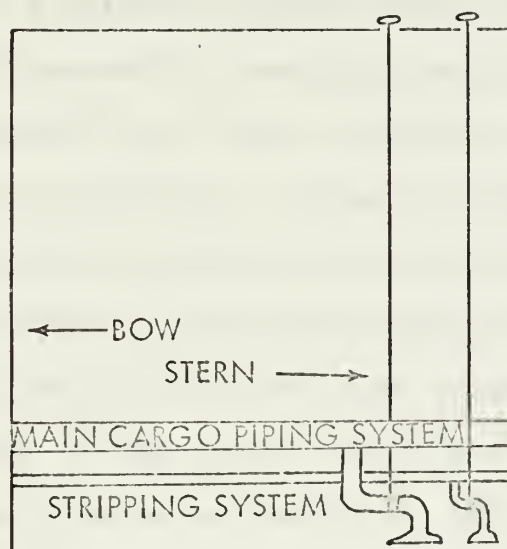


Figure 3 - Main and Stripping Suctions  
in a Cargo Tank

As soon as suction is lost by the main cargo pump system, the stripping system is activated. This system is independent of the main cargo system and removes as much water as is possible with the use of a pump. As soon as stripping is completed and the vessel has passed inspection, cargo loading is commenced.





## Tank Drying

In the case of a vessel loading JP4, as soon as stripping is completed in the forward tanks, they are sealed off from the after tanks by means of pipeline block valves. All tank valves are opened allowing any water remaining in the pipelines forward of the block valves to drain back into the tanks. Men with buckets and mops proceed down into each tank which is from 40-45 feet deep. The remaining water which consists of about 25 gallons per wing tank and 40-50 gallons per center tank is removed by scooping the water into buckets and lifting the buckets on a line, by hand, to the top of the tank where they are poured out. After the water quantity is very low, mops are used in place of the scoops and wrung out by hand into the buckets. Some ships use portable eductors for the removal of water, and some have compressed air motors to raise the buckets to the top of the tank. A tank is considered dry when no free water remains. The drying procedure is repeated in each of the 26 cargo tanks aboard a T2 and requires from 4 to over 100 hours. Drying time, as recorded on the cargo papers, starts when the vessel has completed pumping ballast and ends when the last tank is dry.

T2 drying time taken from 12 inspection reports issued in 1966-67 averaged 8.6 hours per ship. Data reported by several classes of ships on 10 loading reports during 1967 indicated an average drying time of 21.4 hours per ship. The average hourly cost to operate a T2 tanker is \$164.00.<sup>4</sup> An



additional cost is incurred while the vessel is at the dock drying tanks since premium rates are paid to men in the tanks.

The hazards of working in a ship's tank can not be over emphasized. The ladders in the tanks are usually damp and slippery. In some ships, the ladders are vertical which makes descent even more dangerous. Even after a thorough machine cleaning, product vapors are sometimes given off which can cause dizziness or asphyxiation. If there is any doubt as to whether a tank is gas free, a gas detector is used to determine if any vapors are present in the tank. Blowers are sometimes required when tank cleaners are working in order to keep the vapor concentrations to a minimum. In addition to the breathing problem caused by vapors, an explosive mixture in the tank is very dangerous, especially when lamps are lowered to assist in the tank cleaning operation.

### Cargo Loading

After tank drying has been completed and the ship passes inspection, cargo loading is commenced. Cargo is loaded from the manifold on deck either through drop lines which run vertically into the lower pipelines in tanks 5 center and 7 center or back to the pump room, down vertical piping and up the fore and aft lines into the ship's cargo tanks. Figure 4 shows the main piping system of a T2 tanker.



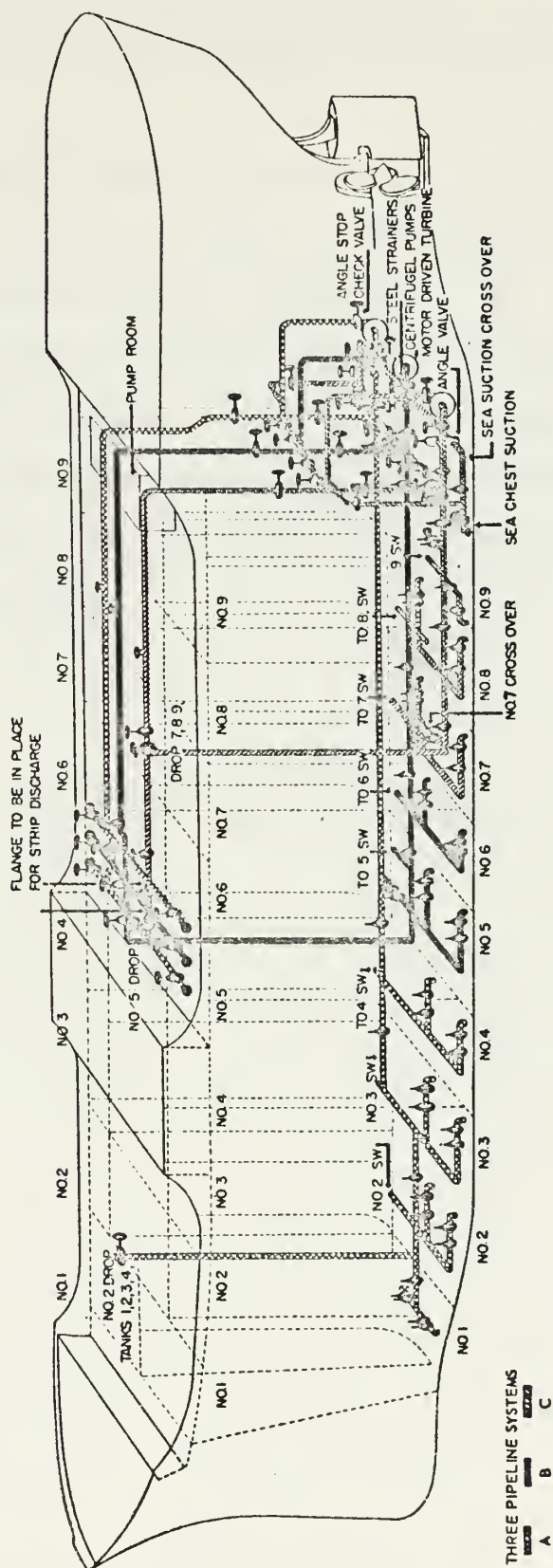


Figure 4. - Pipeline and Valve System of a T-2 Tanker<sup>5</sup>



Summary

Vessels lifting JP4 cargoes are faced with the following problems.

1. Costly drying time at the pier prior to loading.
2. Danger of injury to personnel due to falls or asphyxiation in ships' tanks.
3. Vessels lifting successive JP4 cargoes must clean tanks while enroute to the next loading port. This cleaning operation increases fuel consumption and reduces speed. It would not be required if tank drying were eliminated.





# CHAPTER III

## THE ADDITIVE, ITS PROPERTIES AND INJECTION PROCEDURES

### Introduction

The military specification requirement for JP4 icing inhibitor may be found in Appendix B. The inhibitor consists of 99.6 per cent ethylene glycol monomethyl ether and 0.4 per cent glycerol by weight. The major component provides the icing protection desired while the minor component is added to protect the interior coatings of aircraft fuel tanks. The additive is soluble in jet fuel from 30 to 100 times its specified concentration of 0.10 to 0.15 per cent by volume.<sup>6</sup> It is completely soluble in water either entrained in or in contact with the fuel. The additive is uniquely suited to its purpose since it will migrate to water in contact with fuel in a predictable but not excessive manner. Even though the additive will migrate to water, its equilibrium concentrations in both free water and the fuel are most desirable in accomplishing its purpose.

### The Partition Coefficient

A substance which is soluble in both phases of a two phase liquid system will distribute itself between the two phases. When equilibrium is reached, the ratio of the concentrations of the substance in the two phases is called the partition coefficient. At constant temperature and pressure



the partition coefficient remains constant.<sup>7</sup> The amount of additive which will be absorbed by a particular quantity of water depends on the temperature, the fuel/water ratio and the concentration of the additive in the fuel. All of these effects may be taken into account by means of a partition coefficient. The partition coefficient (K), is defined below.

If:  $(A_f)_0$  = volume of additive in the fuel initially

F = volume of fuel

$W_0$  = initial volume of water in contact with the fuel

$A_w$  = volume of additive in water at equilibrium

$A_f$  = volume of additive in fuel after equilibrium

W = volume of water including the additive after equilibrium

$$\text{Let } y = \frac{A_f(\text{volume})}{F(\text{volume})} \text{ and } x = \frac{A_w(\text{volume})}{W(\text{volume})}$$

$$\text{Then } K = \frac{x}{y}$$

The volume of additive which migrates to the water can be determined as follows:

$$\frac{KA_f}{F} = \frac{A_w}{W}$$

$$W = W_0 + A_w$$

$$\frac{KA_f}{F} = \frac{A_w}{W_0 + A_w}$$

$$\frac{K [(A_f)_0 - A_w]}{F} = \frac{A_w}{W_0 + A_w}$$



$$\left[ \frac{K}{F} (A_f)_o - \frac{K}{F} A_w \right] [W_o + A_w] = A_w$$

Multiplying

$$\frac{KW_o(A_f)_o}{F} - \frac{KW_o A_w}{F} - \frac{K(A_f)_o A_w}{F} - \frac{K A_w^2}{F} - A_w = 0$$

Changing signs and rearranging

$$\left[ \frac{K}{F} \right] A_w^2 - \left[ \frac{K W_o}{F} - \frac{K (A_f)_o}{F} + 1 \right] A_w - \frac{KW_o (A_f)_o}{F} = 0$$

If the K value is known, the equation may now be solved by the quadratic formula.

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad \text{or}$$

$$A_w =$$

$$\frac{-\left[ \frac{K W_o}{F} - \frac{K(A_f)_o}{F} + 1 \right] \pm \sqrt{\left[ \frac{K W_o}{F} - \frac{K(A_f)_o}{F} + 1 \right]^2 - 4 \left[ \frac{K}{F} \right] \left[ \frac{KW_o(A_f)_o}{F} \right}}{2 \left[ \frac{K}{F} \right]}$$

The percentage of additive in the water is determined as follows:

$$A_w(\%) = \frac{A_w (100)}{A_w + W_o}$$

The Research and Development Department of the Phillips Petroleum Company has determined the partition coefficient (K) of military icing inhibitor to be 220 at 80°F.<sup>8</sup> It is this value



which will be used in the thesis computations since the laboratory tests were conducted at approximately 80°F. The three factors which affect the quantity of additive absorbed into a water phase are discussed below.

### 1. Temperature

As the temperature decreases, the partition coefficient increases. More of the additive migrates to the water phase, which is exactly what is required to prevent the water from freezing as the temperature drops. Under all conditions encountered thus far in aircraft fuel tanks, additive migration has not significantly depleted the additive content of the fuel itself.<sup>9</sup> The Phillips Petroleum Company has determined the partition coefficient at 0°F to be 480. It is assumed that a reasonable estimate of the partition coefficient at any temperature may be determined by using the relationship shown in Figure 5.<sup>10</sup>

### 2. Fuel/Water Ratio

The fuel/water ratio affects the migration of the additive to free water. As the fuel to water ratio increases, the amount of additive which migrates to the water increases.

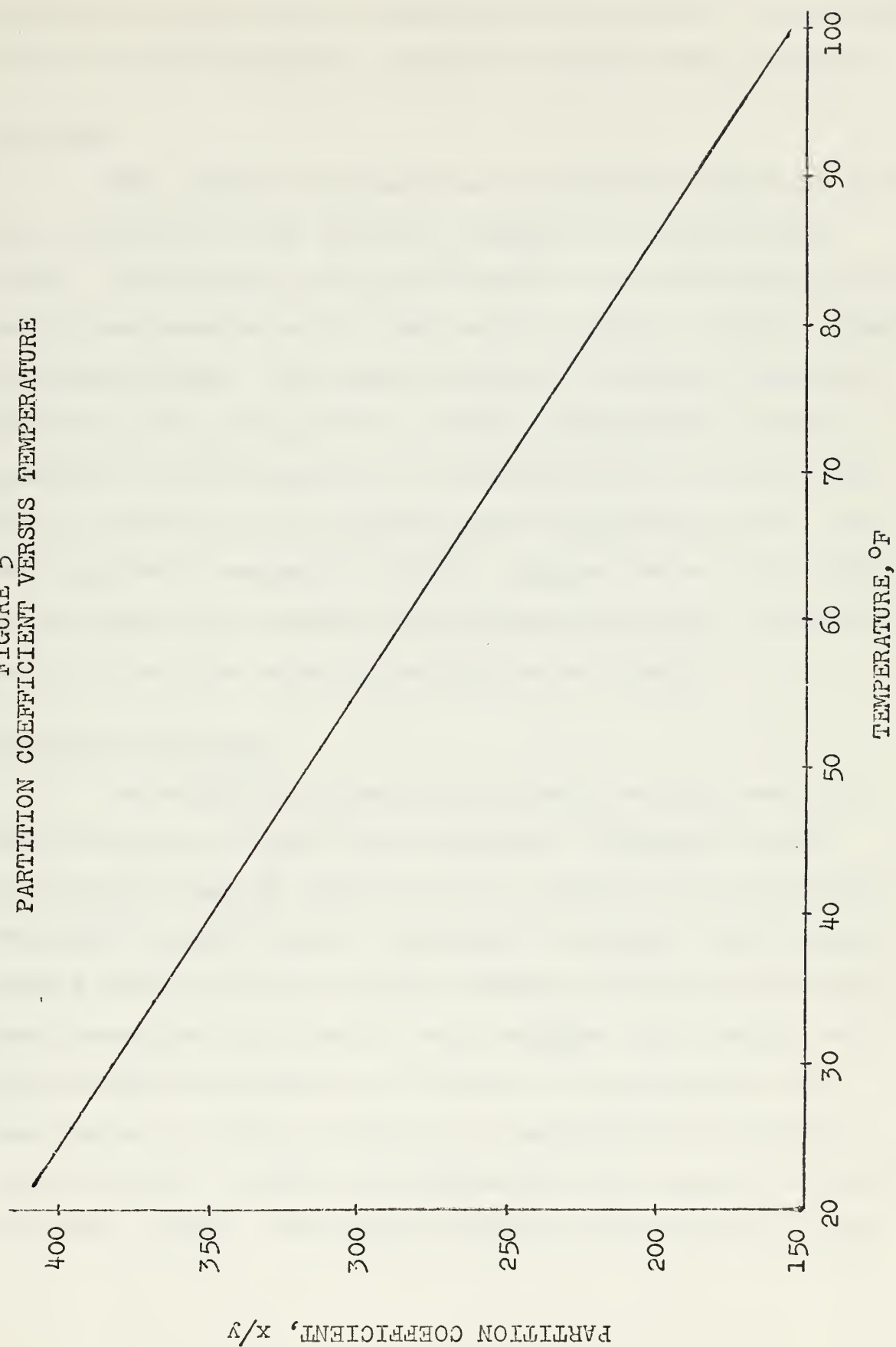
### 3. Additive Concentration in Fuel

The quantity of icing inhibitor which migrates to the water phase is also dependent on the additive concentration in the fuel. As the additive concentration in the fuel is in-





FIGURE 5  
PARTITION COEFFICIENT VERSUS TEMPERATURE





creased the percentage of additive which migrates to the water phase is also increased. Figure 6 indicates this property.

### Glycerol

The glycerol component in the additive serves to prevent softening of the interior coatings of aircraft fuel tanks. An aircraft wing tank interior is not subject to softening when exposed to dry fuel with or without ethylene glycol monomethyl ether. The tank interior is, however, subject to softening and peeling when in contact with water, and this condition is accelerated if the interior is in contact with water containing only ethylene glycol monomethyl ether. The minor glycerol component actually reduces the softening effect of the water and ethylene glycol monomethyl ether combination to less than that experienced with water alone.<sup>11</sup>

### Biocidal Protection

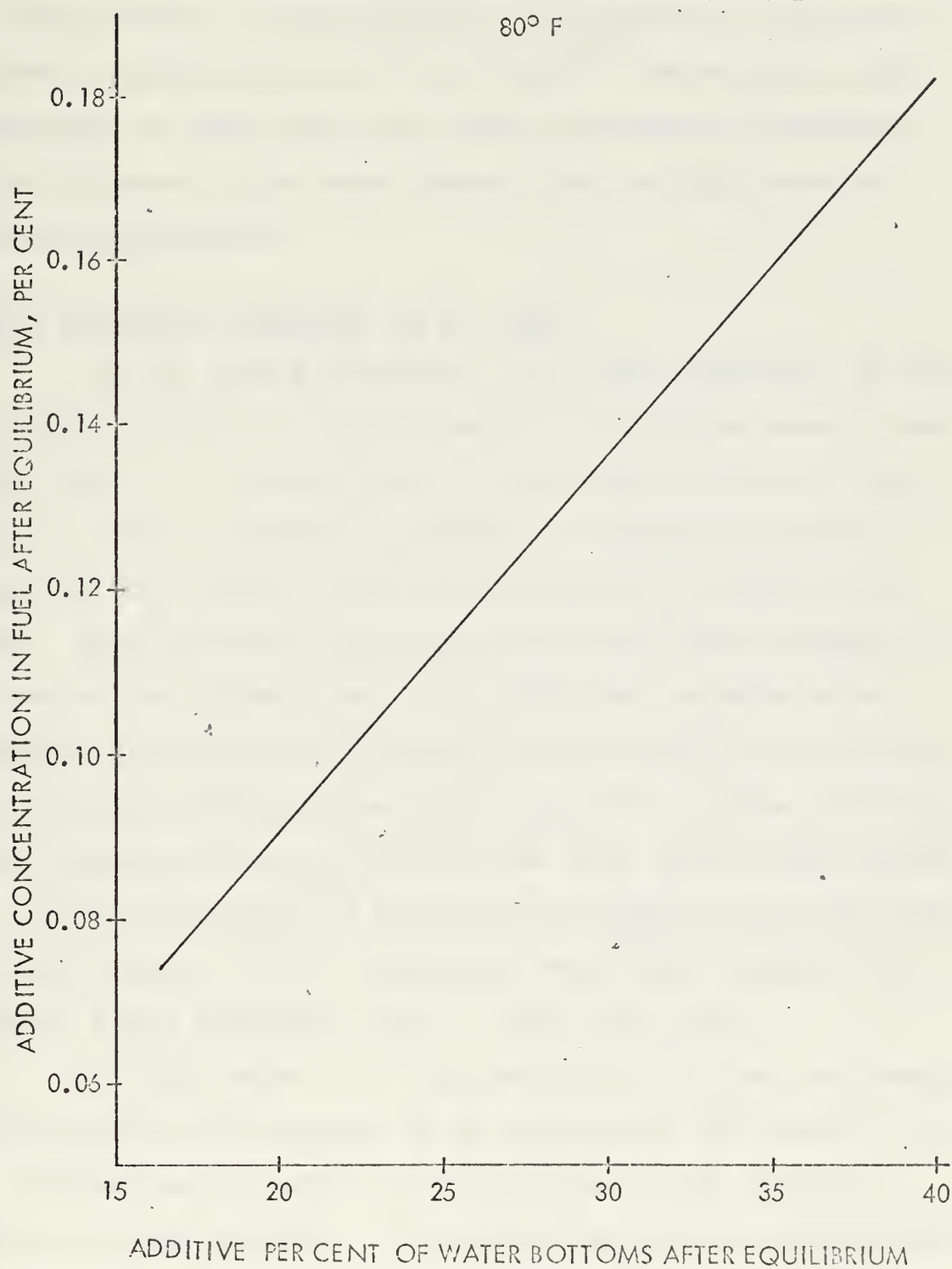
An additional beneficial property was discovered in the development of the icing inhibitor. Ethylene glycol monomethyl ether was found to be an excellent biocidal agent. Microbial growths in the wing tanks of aircraft have always caused concern to the aircraft industry since once the organisms penetrate the interior tank coatings, the aluminum surfaces below are subject to corrosion. The organisms must have water to exist and thrive at the fuel-water interface since the fuel provides the hydrocarbon food supply necessary for their growth. The icing inhibitor which migrates to the



FIGURE 6

ADDITIVE PER CENT OF WATER BOTTOMS AT EQUILIBRIUM  
VERSUS ADDITIVE CONCENTRATION IN FUEL

80° F





water phase promptly kills new microbial growths before they can multiply in addition to controlling existing slime growths or fungal mats. A lethal mixture of additive in water requires a concentration of 15 per cent.<sup>12</sup> Fortunately, this percentage is well below the normal percentage of additive which migrates to the water phase, thus assuring constant biocidal protection.

### Icing Inhibitor Injection in Jet Fuel

As was stated previously, the icing inhibitor in use is highly soluble in JP4 and remains in solution once it has been added. If the additive is to be injected into a shore tank of JP4, the product is normally circulated through a pump and the additive added incrementally up stream of the pump. Some refineries have facilities for line blending upstream of the product pump, and sufficient turbulence is created in the pump and through the remaining line to insure satisfactory mixing by the time the product reaches the ship. Line blending of icing inhibitor not only permits the refiner to add any percentage of the additive desired, but also saves storage capacity since contractors may obtain product with or without icing inhibitor from the same shore tank.

At this point it is appropriate to discuss the reason for requiring the additive to be injected in JP4 which is to be transported by vessel, vice injection at the discharge port or at the airfield. The demand for and the distribution of JP4 is great. Large demands from activities all over the





world require careful distribution planning. Even with the most sophisticated planning techniques, it is not uncommon for vessels to be diverted to a different discharge port than the one specified at the time of loading. Since it would be too costly to install icing inhibitor injection equipment at every discharge port, each vessel must carry ready-to-use product in order to maintain flexibility. To install an injection system aboard each ship would be costly and wasteful since clean product ships carry a variety of products, and increased equipment weight would reduce the pay load, to say nothing of the problem of obtaining and storing the additive aboard the vessel. The fact that such large quantities of jet fuel are contracted for is another factor. Undoubtedly, the additional cost of icing inhibitor delivered to one refinery location for jet fuel under a large contract is much lower than if the inhibitor were required to be delivered and stored at discharge ports or airfields throughout the world. It would be most desirable if icing inhibitor were available at each location; however, high cost equipment and transportation charges make this arrangement prohibitive. Some activities do have injection equipment but if flexibility is to be maintained, product must be purchased in the ready-to-use form.



## CHAPTER IV

### TEST METHODS FOR THE ADDITIVE AND LABORATORY PROCEDURES

#### Introduction

The Department of Defense has approved two methods for determining the icing inhibitor content of jet fuel. Both methods are acceptable when the icing inhibitor concentrations are in the range 0.05 to 0.20 volume per cent.

#### Refractometer Method

The most recent method to be accepted is the differential refractometer method. The test consists of removing the ethylene glycol monomethyl ether and glycerin from the hydrocarbon fuel by extraction with water. The amount of icing inhibitor in the extract is determined by measuring the difference between its refractive index and that of the water used in making the extraction. Federal Test Method 5340, dated 1 July 1965, describes the procedure in detail and is included as Appendix C.

#### Potassium Dichromate-Acid Method

An alternate method to determine the icing inhibitor concentration in a hydrocarbon fuel is described in Federal Test Method 5327.3, dated 1 July 1965. This method was the first to be accepted by the military and was used exclusively in procurement inspections until early 1966. The author



selected this method of determination for the thesis tests described in Chapter V. The glassware and reagents were easily obtained. Many petroleum testing laboratories, both military and commercial, continue to use this test since it is considered the more reliable of the two. This method also requires the extraction of the icing inhibitor with water. The water solution is allowed to react with an excess of standard potassium dichromate solution in the presence of sulfuric acid and the excess dichromate is determined idometrically. A copy of this test method is included as Appendix D.

#### Reagents

The reagents used are listed in Appendix D, paragraph 4. The required solutions were prepared in accordance with the test method, using accepted laboratory practices. The sodium thiosulfate solution was standardized weekly.

#### Apparatus

A list of the required apparatus may be found in Appendix D, paragraph 3. For ease of operation the following pieces of equipment were substituted for those listed in the test method.

1. Two, 1 gallon glass bottles on an elevated stand were used to refill two, 50 milliliter automatic zero burets. These bottles contained the potassium dichromate and sodium thiosulfate standard solutions.
2. Two, 25 milliliter pipets were used. One was used



exclusively for JP4 and the other exclusively for distilled water.

3. A 250 milliliter iodine flask was used vice a 500 milliliter iodine flask since the 500 milliliter flasks were not readily available.

### Specimens

#### 1. Jet Fuel

Approximately 20 gallons of JP4 were used in the laboratory tests. An analysis of the fuel used may be found in Chapter V, page 44. The fuel obtained had not previously been treated with any icing inhibitor.

#### 2. Icing Inhibitor

One gallon of icing inhibitor meeting military specifications was obtained for use in the laboratory experiments. The results of several tests run by a commercial laboratory on the tank from which the gallon sample was taken are listed on page 27.





<u>Test</u>	<u>Specification Requirement</u>	<u>Sample Results</u>
Acid number, mg. KOH/gm.	0.09 Max.	0.06
Glycerol, Wt.%	0.36-0.44 Limits	0.37
Color, platinum cobalt	20 Max.	Lighter than 20
pH of 25% solution in water at $25^{\circ} \pm 2^{\circ}\text{C}$	6.0 to 7.0 Limits	6-7
Refractive index, ( $25^{\circ}\text{C}$ )	1.4000-1.4010 Limits	1.4010
Specific gravity ( $20^{\circ}/20^{\circ}\text{C}$ )	0.965-0.969 Limits	0.967
Water, % Wt.	0.2 Max.	0.08

### 3. Sea Water

Sea Water used in the experiments was prepared by mixing tap water with synthetic sea salts purchased from Aquarium Systems Incorporated, 1450 East 289th Street, Wickliffe, Ohio, under the trade name of "Instant Ocean."

### "F" Factor Determination

An "F" factor determination must be made on each new blend of icing inhibitor used. The factor "F" is the milliliters of methyl cellosolve-glycerin per milli-equivalent of potassium dichromate and is determined as follows. Five milliliters of a 0.1 per cent methyl-cellosolve glycerin solution were transferred to a pyrex test tube. Ten milliliters of .2N potassium dichromate were added from a buret, and the test tube was placed in an ice bath. After allowing the solution to cool, 5 milliliters of concentrated sulfuric acid were added. The acid was added very slowly, and the test tube



was continually agitated in the ice bath to insure that thorough mixing occurred and that the temperature of the solution did not rise significantly. After the acid had been added, agitation was continued for approximately one minute after which the test tube was placed in a bath of boiling water for exactly 10 minutes. The test tube was then returned to the ice bath until the contents had cooled below room temperature. The contents were then transferred to a 250 milliliter iodine flask. The test tube was washed 4 times with 5 milliliter portions of distilled water and the washings added to the flask. Approximately 3 grams of potassium iodide were added to the contents in the flask. Care was taken to insure that any iodine vapor which formed was kept in the flask. The titration of the solution was commenced, adding sodium thiosulfate to the flask by buret while constantly swirling it until the brown solution turned to a yellowish-green. Two milliliters of starch indicator solution were then added and the titration was slowly continued until the color changed sharply from dark blue to light bluish-green. The milliliters of thiosulfate required were recorded. The "F" factor was determined as follows:

$$F = \frac{B}{(V_d N_d) - (V_t N_t)}$$

where B = milliliters of methyl cellosolve-glycerin in aliquot of standard solution analyzed.



$V_d$  = milliliters potassium dichromate

$N_d$  = normality of potassium dichromate

$V_t$  = milliliters sodium thiosulfate

$N_t$  = normality of sodium thiosulfate

The icing inhibitor used in the thesis tests had the "F" factor listed below based on three determinations yielding the same result to three significant figures.

$$B = 0.00500$$

$$V_d = 10.00$$

$$N_d = 0.200$$

$$V_t = 14.20$$

$$N_t = 0.100$$

$$F = \frac{0.00500}{(0.200)(10.00) - (14.20)(0.100)} = 0.00362$$

In the initial determination of the "F" factor, which was the author's first experience with the test, three samples were run simultaneously, each step being performed on the three samples in succession. The three values of "F" increased for each successive sample. Results of various sets of three tests run on a 0.1 per cent solution of the additive in water are shown below.

Milliliters of Sodium Thiosulfate Required  
in Four Sets of Tests

	<u>Set 1</u>	<u>Set 2</u>	<u>Set 3</u>	<u>Set 4</u>
Sample 1	13.75	13.85	13.90	13.85
Sample 2	13.85	14.00	13.95	13.90
Sample 3	14.00	14.05	14.10	14.05





After many timed experiments it was concluded that time was indeed a factor between the addition of the acid and the placement of the solution into the boiling water bath. The solution which received the acid first, even though it remained in the ice bath, required less thiosulfate, indicating that the oxidation process was taking place during this period. In order to solve this problem tests were run, one at a time, through the entire process, insuring that each solution was subjected to the same time interval in each step of the test. Several sets of three tests were run on different solutions and the "F" values on each solution were the same to three significant figures. All following tests were, therefore, run in this manner.

#### Analysis of the Fuel

Twenty-five milliliters of the test fuel and 25 milliliters of distilled water were transferred by pipet into a dry 125 milliliter separatory funnel. The separatory funnel was shaken vigorously for 2 minutes. After the water and fuel had separated, the water layer which had extracted the additive was drained into a 50 milliliter Erlenmeyer Flask. Five milliliters of this solution were then transferred to a test tube by means of a pipet.

The test method from this point is exactly as that described in the determination of the "F" factor. The milliliters of sodium thiosulfate required to reach the end point were used to determine the icing inhibitor concentration





in the fuel as follows:

$$\text{Per Cent Concentration} = \frac{100 F [(V_d N_d) - (V_t)(N_t)]}{AS}$$

Where A = aliquot fraction of water extract used

S = milliliters of hydrocarbon fuel sample

Other symbols are identified under "F" factor determination.

Care was taken to insure that the end point was not passed. Once the end point is reached, any quantity of thio-sulfate may be added to the solution without a color change occurring. As the end point was approached, one drop of thio-sulfate at a time was added in order to prevent inadvertently passing the end point.

#### Blank Determination

A blank determination was performed prior to any additive treatment in order to determine components inherent in the fuel which would react during the test and provide misleading results. The same method is used as for a fuel containing icing inhibitor. Three determinations were made, all of which yielded the same result to three significant places.

$$\text{Blank Value} = \frac{100 F [(V_d N_d) - (V_t N_t)]}{AS}$$

$$F = .00862$$

$$V_d = 10.00$$

$$N_d = 0.200$$



$$V_t = 19.50$$

$$N_t = 0.100$$

$$A = \frac{5.00}{25.00}$$

$$S = 25.00$$

$$\text{Blank value} = \frac{100(.00862)[(10.00)(0.200) - (19.50)(0.100)]}{\frac{5.00}{25.00} \times 25.00} =$$

$$0.009$$

The blank determination was subtracted from each test result in order to obtain the actual icing inhibitor concentration in the fuel.



$$V_t = 19.50$$

$$N_t = 0.100$$

$$A = \frac{5.00}{25.00}$$

$$S = 25.00$$

$$\text{Blank value} = \frac{100(.00862)[(10.00)(0.200) - (19.50)(0.100)]}{\frac{5.00}{25.00} \times 25.00} =$$

$$0.009$$

The blank determination was subtracted from each test result in order to obtain the actual icing inhibitor concentration in the fuel.



## CHAPTER V

### LABORATORY TESTS

#### Purposes

Laboratory tests were conducted for the following purposes:

1. To determine if physical test results would confirm mathematical predictions of additive concentration in fuel and sea water mixtures, based upon available data for the partition coefficient of the anti-icing additive.
2. To perform tests which would indicate if additive equilibrium could be established in the fuel and water phases by the time a tanker completed loading.
3. To investigate the effect that temperature changes have on additive equilibrium concentration in mixtures of fuel and sea water.
4. To determine if sea water in the ship's tanks would have any effect on the quality of the jet fuel.

#### Confirmation of Mathematical Predictions

In order to determine if additive concentrations at equilibrium could be predicted from available partition coefficients, two groups of laboratory tests were run. All tests were performed at room temperature unless otherwise specified. Prior to running the first group of tests, the fuel to be





used was saturated with sea water by agitation in a volumetric flask. Care was taken to insure that no free water was transferred to the test flask along with the saturated fuel. Enough fuel was transferred to the test flask to nearly fill it; however, sufficient space was allowed for the addition of the additive and sea water. Icing inhibitor was injected into the flask by means of a pipet. The flask was then agitated to mix the additive in the fuel. Sea water was injected by means of a syringe followed by enough fuel to bring the flask to volume. The flask was again agitated to speed up the equilibrium process.

The volume of additive expected to migrate to the water phase was determined mathematically by using the formula derived in Chapter III, page 16. The K value used was 220 since the temperature at which the tests were conducted was approximately 80° F. The percentage of additive expected to remain in the fuel was determined as follows:

$$A_f(\%) = \frac{[(A_f)_0 - A_w]100}{F}$$

where  $(A_f)_0$  = initial volume of additive in fuel

$A_w$  = additive volume in water at equilibrium

F = fuel volume

Table 1 indicates the results of the tests conducted.



TABLE 1

LABORATORY MEASUREMENT OF ADDITIVE CONCENTRATION IN  
SATURATED FUEL VERSUS MATHEMATICAL PREDICTION

Component Quantities in Milliliters			Per Cent	Per Cent
Saturated Fuel	Additive	Sea Water	Lab. Measure of Additive Concen. in Fuel at Equilib.	Mathe- matical Predic- tion
998.0	1.5	0.5	0.129	0.130
997.3	1.7	1.0	0.132	0.130
996.2	1.8	2.0	0.114	0.114
996.6	1.8	1.6	0.123	0.122

Since the additive was mixed into the fuel prior to the addition of water, test results after water contact indicated a decreasing additive content in the fuel until equilibrium was established. The flasks were periodically agitated and tests were conducted until the same test results were continually obtained, indicating that equilibrium was established. Even though only four tests were conducted, it is considered significant that most of the results were within 0.001 per cent concentration of the predicted value.

The second group of tests were conducted in a similar manner to the first group; however, the fuel used was not saturated with sea water. Table 2 indicates the results of the second group of tests. Table 2 clearly shows that the



TABLE 2

LABORATORY MEASUREMENT OF ADDITIVE CONCENTRATION  
IN FUEL VERSUS MATHEMATICAL PREDICTION

Component Quantities in Milliliters		Per Cent	Per Cent	Per Cent
Unsaturated Fuel	Additive	Sea Water	Lab. Measure of Additive Concn. in Fuel at Equilib.	Mathematical Prediction if 80 ppm Water was Absorbed
99.749	0.151	0.10	0.120	0.117
99.789	0.151	0.06	0.134	0.128
997.41	1.750	0.84	0.150	0.139
998.33	1.460	0.21	0.144	0.137
1996.2	3.000	0.80	0.144	0.134





mathematical predictions were not confirmed by the tests. The fuel will hold approximately 80 parts per million of water at room temperature.<sup>13</sup> Table 2 also indicates the mathematically predicted concentration, assuming that the fuel absorbed 80 parts per million of the injected water. The laboratory test results are somewhat closer to this revised prediction. The mixtures listed under Table 2 were subjected to much more agitation than those listed under Table 1, and it is believed that the agitation was a factor in the result. The interior of the flasks in the second group of tests were coated with beads of water. It is believed that the dispersion of the water reduced its ability to absorb additive because in some flasks water beads were up above the fuel level, which reduced the water available to absorb additive. Care was taken in agitating the flasks in the first group to insure that the water remained as one phase in the bottom of the flask.

The tests conducted indicate that when a vessel is loaded, the icing inhibitor concentration at equilibrium will very likely be slightly higher than the mathematical prediction. It is concluded, however, that equilibrium concentrations may be easily predicted within the range of the military specification.

#### Equilibrium Times

After a vessel has been loaded with cargo it is normally not permitted to leave its berth until laboratory tests





are run on a ship's composite sample to insure that the product meets specification requirements. If a vessel is loaded as the author proposes, fuel will be pumped to the ship containing sufficient icing inhibitor to satisfy the following requirements.

1. An amount which will be absorbed by the ballast residue aboard the vessel.
2. An amount to satisfy the desired icing inhibitor content of the fuel itself after additive absorption in the water bottoms has occurred.

The time required for the additive in the water and in the fuel to reach equilibrium must be taken into consideration. Since anti-icing tests will be run on the ship's composite sample, the rate of attainment of equilibrium for the additive must be known.

Laboratory tests were run on several samples in an effort to determine the time required for equilibrium to be established. Table 3 indicates the results of these tests. Samples were vigorously shaken for approximately five minutes immediately after preparation and randomly throughout the testing period.

It should be noted that the first two samples in Table 3 were prepared by mixing the additive in the fuel prior to the addition of water, while the last two were prepared by mixing the additive in a small quantity of fuel and the water. The balance of the fuel was then added after the



TABLE 3

TIME REQUIREMENTS FOR ADDITIVE EQUILIBRIUM TO BE ESTABLISHED  
IN FUEL AND SEA WATER

Initial Composition		Additive Concentration in Fuel After Time Specified							
Per Cent		Per Cent							
Additive Sea Water	0.175	0.084	5 Min.	5 Hrs.	17 Hrs.	22 Hrs.	45 Hrs.	6 Days	9 Days
			0.170	0.155	0.150	0.150	0.150	0.151	0.149
Additive Sea Water	0.175	0.084	1.5 Hrs.	18 Hrs.	4 Days	7 Days			
			0.158	0.150	0.151	0.152			
Additive Sea Water*	0.146	0.021	1 Hr.	18 Hrs.	66 Hrs.	4 Days			
			0.142	0.144	0.144	0.144			
Additive Sea Water*	0.15	0.05	11 Hrs.	14 Hrs.	20 Hrs.	36 Hrs.			
			0.128	0.130	0.129	0.129			

\*Sample was prepared adding sea water and icing inhibitor in approximately 250 milliliters of fuel. Sufficient fuel was then added to bring volume to 1000 milliliters. This accounts for the initial low additive concentration since the additive was migrating from the water phase to the fuel phase.



flask had been agitated. Table 3 indicates the result. In the first two samples the additive was migrating from the fuel to the water phase, while in the last two the migration was taking place in reverse order. The time required for equilibrium was approximately eighteen hours.

It was realized that the means by which the samples in Table 3 were mixed could not be compared with the mixing which would take place on board a ship. In an effort to simulate more closely the mixing that would take place aboard ship another test was conducted. A 10 gallon can was obtained and fuel containing icing inhibitor was siphoned with approximately a 10 foot head through three-sixteenths inch glass tubing and into a pipe which extended from the top to the bottom of the can. Sea water was placed in the bottom of the can so that any fuel entering the can had to pass through the pipe and come in contact with the water. This would be very similar to the mixing process which would occur in a ship. It became evident after commencing the test that the turbulence at the bottom of the can was not similar to that witnessed in loading a ship. Even after a ship's tank is nearly full, product motion may be seen by looking into the tank. In the case of the experiment, no motion could be seen even after one inch of product had been siphoned into the can. The test was continued, however, in order to see what the equilibrium time would be. The can was allowed to remain motionless for approximately two days and the test results shown in Table 4 were obtained during this period.





TABLE 4

TIME REQUIREMENTS FOR ADDITIVE EQUILIBRIUM TO BE  
ESTABLISHED IN FUEL AND SEA WATER

---



---

Starting Conditions	
Additive Concn. in Fuel = 0.175%	
Water Volume = 0.120%	
After Time Specified	Concentration In Fuel (Per Cent)
20 Min.	0.170
2.7 Hrs.	0.166
8.2 Hrs.	0.163
19.5 Hrs.	0.156
26.7 Hrs.	0.151
31.7 Hrs.	0.150
44.7 Hrs.	0.144

---



---

A device was constructed which would provide a rocking motion to the container. The container was supported in a cradle. A connecting rod moved by a cam attached to a motor shaft on one end and the cradle base on the other provided approximately a 20 degree swing on both sides of vertical. The rate of movement was approximately 40 cycles per minute. The rocking device was turned on and the container was in motion for the remainder of the testing period. The results shown below were obtained during this period.





<u>After Time Specified</u>	<u>Additive Concentration In Fuel (Per Cent)</u>
3 Hrs.	0.140
9 Hrs.	0.139
22 Hrs.	0.134
50 Hrs.	0.134

The author concluded from these tests that there is a very good possibility that equilibrium will not be established by the time a tanker completes loading. The time required to load a tanker with JP4 is dependent on many factors. An average loading time for a T2 could be expected to be about 15 hours. An anti-icing test result from a ship's composite sample would, therefore, be expected to lie in the range between the initial concentration in the fuel and the calculated concentration at equilibrium. It is, however, possible that the turbulence created in a vessel's tanks will bring the additive much closer to equilibrium than was experienced in the laboratory tests.

#### Temperature Effects

In order to investigate the effect which could be expected when temperature changes occur as a vessel proceeds from one climate to another, the tests shown in Table 5 were conducted.

In extreme cases the fuel temperature aboard ship might get as low as 35°F. The normal temperature range would be 40°F to 90°F. The tests shown in Table 5 merely indicate that if the fuel undergoes a large decrease in temperature the icing inhibitor content will not be seriously depleted.



TABLE 5

## ADDITIVE CONCENTRATION IN FUEL AT VARIOUS TEMPERATURES

---

Initial Conditions at Room Temperature after Equilibrium:  
 Additive Concentration in Fuel = 0.149%,  
 Water = 0.084%

---

Temperature	Time Sample at Specified Temperature	Additive Concentration in Fuel (Per Cent)
32°F	2 Days	0.125
32°F	5 Days	0.119

---

Initial Conditions at Room Temperature after Equilibrium:  
 Additive Concentration in Fuel = 0.152%,  
 Water = 0.084%

---

Temperature	Time Sample at Specified Temperature	Additive Concentration in Fuel (Per Cent)
32°F	2 Days	0.126
32°F	5 Days	0.126
46°F	1 Day	0.142
46°F	2 Days	0.140

---

Salt Water Effect

Table 6 shows JP4 specification requirements and the results of tests run on the fuel both before and after sea water contact. The tests were run by the American Oil Company Laboratory, Sugar Creek, Missouri. Test 1 was run on a sample taken from the same storage tank that the fuel used in the laboratory tests was taken. It contained no icing



TABLE 6

## JP4 SPECIFICATION TEST RESULTS AFTER SEA WATER CONTACT

Test	Specification Requirements	Test 1 Original Fuel	Test 2 Original Fuel	Test 3 After Sea Water Contact
Gravity, °API	45-57.0 Limits	54.2	54.0	53.9
Distillation: Initial Pt., °F	Report	129	141	138
10% Evap., °F	Report	184	192	189
20% Evap., °F	290°F Max.	213	219	218
50% Evap., °F	370°F Max.	276	281	280
90% Evap., °F	470°F Max.	416	411	411
400°F Point, % Evap.	Report	88.0	87.0	87.0
End Point, °F	Report	485	491	493
Residue & Loss, vol. %	1.5 & 1.5 Max.	1.0 & 1.0	1.0 & 1.0	1.0 & 1.0
Reid Vapor Press., psi	2.0-3.0 Limits	2.9	2.8	2.8
Doctor Test	Negative	Negative	Negative	Negative
Corrosion, CuStrip	1b Max.	1A	1A	1A
Smoke Point, mm.	Report	27	26	27
Smoke Volatility Index	52.0 Min.	64.0	64.1	63.5
Existent Gum, mg/100ml.	7.0 Max.	0.6	0.2	0.2
Potential Gum, mg/100ml.	14.0 Max.	1.5	3.2	2.2
Freezing Point, °F	-72 Max.	-90	<-80	<-80
Aromatics & Olefins, vol. %	25.0 & 5.0 Max.	11.1 & 1.6	11.9 & 0.7	11.7 & 0.7
Aniline Point, °F	Report	128.0	128.0	128.0
Aniline-Gravity Product	5250 Min.	6950	6920	6900
Water Reaction	1b Max.	1	1	1
Sulfur, Tot.wt. %	0.4 Max.	0.165	0.138	0.173





TABLE 6  
(Continued)

Test	Specification Requirements	Test 1 Original Fuel	Test 2 Original Fuel	Test 3 After Sea Water Contact
Thermal Stability:				
Pressure Drop, In. Hg.	3.0 Max.	0.3	*	*
Deposit	Less than 3	#1	*	*
Icing Inhibitor (GAFCOL EMG)	0.10-0.15 Limits	Unknown	0.006	0.141
W.S.I.M. (after San.C)	70 Min.	94	91	99
Particulate Contaminant, mg/gal.	4.0 Max.	Unknown	2.1	3.2
Anti-Oxidant (AMOCO 535), Lbs./MBbls.	8.4 Max.	1.25	1.25	1.25
Metal Deactivator (AMOCO 522), Lbs./MBbls.	2.0 Max.	1.25	1.25	1.25
Corrosion Inhibitor, Lbs./MBbls.	4.0-4.5 Limits	None	None	None

\*Insufficient sample quantity to perform test.





inhibitor. Test 2 was run on a sample of the fuel which had not been used in any tests but had been retained in a 5 gallon container during the testing period. This sample should have produced test results duplicate to Test 1. Test 3 was run on the fuel which contained icing inhibitor and which had been exposed to salt water for a period of approximately 24 days. During this period the mixture was intermittently agitated by use of the rocking device.

The results indicate that fuel contact with salt water will have no significant effect on the quality of the fuel.

#### Summary

The following conclusions were drawn from the laboratory tests.

1. If the quantities of fuel, icing inhibitor and water are known in a mixture, the icing inhibitor content of the fuel at equilibrium may be reasonably predicted.
2. In order to determine if equilibrium will be reached by the time a tanker is loaded, tests must be performed actually using a vessel. In any case, after loading has been completed, an icing inhibitor test will indicate if the actual icing inhibitor concentration is within range to meet the desired concentration at equilibrium.
3. The icing inhibitor content of the fuel will not be seriously depleted by temperature changes experienced



while aboard the tanker. It should be noted, however, that in cold weather the additive concentration at equilibrium will be lower than that predicted using a partitioning coefficient of 220. A good estimate of the partitioning coefficient to use when the fuel temperature is not in the 70-80°F range may be found in Chapter III, page 19.

4. The small quantity of salt water remaining aboard a tanker will have no significant effect on the quality of the fuel.



## CHAPTER VI

### COMPUTER SIMULATIONS

#### Introduction

The calculations required to predict additive equilibrium concentrations mathematically are not difficult. They are, however, time consuming since at least 26 separate calculations are required for each tanker. A computer program was written in order to provide a rapid means of determining simulation results. The program also allows the operator to estimate the water quantity remaining aboard the vessel and to see the resulting additive concentration in each compartment due to his estimate. An economic analysis was incorporated into the program comparing the cost of drying tanks with the cost of increasing the additive content in the fuel. Another purpose of the program was to determine a procedure for calculating the additional icing inhibitor required, which could be simplified and done by hand calculation. Appendix E defines the input variables and symbols used in the program. The program itself is included along with input and output examples.

#### Program Operations

The following input data are required by the program.

1. The desired icing inhibitor content of the total cargo after equilibrium has been established.



2. The number of wing tanks the vessel has on each side.
3. The number of center tanks the vessel has.
4. The additional cost per gallon of product for increasing the icing inhibitor content above the specification maximum of 0.15 per cent. The condition which warrants a cost increase may seem somewhat unrealistic, yet it was taken from a past military jet fuel contract.<sup>13</sup> For example, if the icing inhibitor concentration is required above 0.150 per cent, the additional cost per gallon of product is the same regardless of whether the concentration is 0.155 per cent or 0.180 per cent. It is anticipated that if the method of loading described in this thesis became common, cost increases would be established for incremental increases in additive concentration. The method of determining the cost for additional inhibitor was used only because it represented real life conditions which existed at the time the thesis was written.
5. The hourly cost to operate the type tanker being simulated. The costs used in this thesis were obtained from the Military Sea Transportation Service, Washington, D.C.
6. An estimate of the amount of water which will remain aboard the tanker after it has been stripped dry. This data is optional. If it is omitted, the program





calculates the equilibrium concentrations with the actual water input data supplied. If an estimate is made, the estimated water is used to determine the icing inhibitor concentration of the fuel supplied to the ship. The average equilibrium concentration is calculated on the basis of actual water in the tanks and the effect of a bad estimate may be evaluated.

7. The actual fuel quantity to be loaded in each ship's tank.
8. The actual water quantities which exist in each ship's tank.

The icing inhibitor concentration supplied in the fuel to the ship is determined in the following manner. A pre-selected average additive absorption percentage is set by the desired average additive concentration at equilibrium. This percentage is multiplied by the total actual water on board to determine the average amount of additive which will be absorbed by the water. The desired additive concentration at equilibrium is multiplied by the total barrels of fuel loaded to determine the barrels of additive required in the fuel at equilibrium. The two icing inhibitor quantities calculated are added and divided by the total fuel. This figure multiplied by 100 is the additive percentage to be injected into the fuel pumped to the vessel.

The actual additive concentration in each ship's tank



is then calculated by the formula derived in Chapter III. Each tank's fuel quantity is then multiplied by its respective additive concentration at equilibrium. The barrels of additive in each tank are summed and divided by the total fuel in order to determine the average cargo additive concentration at equilibrium.

The economic analysis simply compares the cost of additional additive with the cost incurred at various drying times and provides the difference either in dollars saved or additional cost incurred.

#### Program Data

The data used in the computer simulations were obtained from several sources. The fuel quantities were taken from past T2 tanker loading reports supplied by the Military Sea Transportation Service, Washington, D.C.

The quantity of water which remains aboard a tanker after the vessel has been stripped dry is dependent upon several factors. The condition of the pipelines, the condition of the stripping pump, and the trim of the vessel all affect the amount of water which may be removed. The author's experience in loading tankers provided him with a good estimate as to the average amount of water remaining in a T2. In order to use the best possible data, approximately 30 questionnaires were sent to operating tankers. Eight replies were received. The replies came from a number of sources, including first officers, shore pumpmen, Captains, and military



petroleum inspectors. None of the estimates received differed greatly from any other. Below is the average estimated water quantity per tank taken from the 8 replies received.

Figures are in U.S. Gallons

<u>Tank No.</u>	<u>Starboard</u>	<u>Center</u>	<u>Port</u>
1	13	--	13
2	13	36	13
3	13	19	13
4	18	42	18
5	16	24	16
6	17	47	17
7	22	28	22
8	21	59	21
9	34	36	34

Various computer simulations were run using the water quantities above. The fuel quantities used were taken from actual tanker loading reports. All of the figures referred to below are reductions of actual computer output pages. The icing inhibitor concentrations shown on the vessel diagrams are concentrations in the fuel at equilibrium. All fuel and water quantities shown on the figures are in barrels. The first simulation was performed using a desired additive concentration in the fuel at equilibrium of 0.14 per cent. Figure 7a indicates the average additive concentration at equilibrium to be 0.139 per cent. It is significant that fuel with an additive concentration of only 0.144 per cent had to be loaded aboard the ship to attain the desired result. Figures 8a, 9a, and 10a use the same fuel and water quantities;





however, water estimates are made. In Figure 8a, it was estimated that 50 per cent less water was aboard the ship than actually existed. The average additive concentration in fuel at equilibrium dropped only 0.002 per cent to 0.137. In Figure 9a, fifty per cent more water was estimated aboard the ship than actually existed. The final average concentration was 0.140 per cent and the percentage of additive required to be added in the fuel pumped to the ship still did not exceed the maximum specification limit. In Figure 10a, one hundred per cent more water was estimated than existed. The results were still within specification limits. In all cases, the vessels could have been loaded without drying tanks. The dollars saved appear on the economic analysis data sheets, Figures 7b, 8b, 9b, and 10b.

Figure 11a shows the result of input data requiring a 0.15 per cent average concentration of icing inhibitor in the fuel at equilibrium. In this case, the concentration of additive in the fuel pumped to the vessel exceeds the maximum specification limit of 0.150 per cent. The cost for the additional additive is, therefore, taken into consideration in the economic analysis, Figure 11b. It would be less expensive to load this vessel by the new method only if the drying time was known to be greater than 12.6 hours.

### Summary

The computer simulations indicate that there is a very good possibility that T2 tankers may be loaded without drying





tanks and without any additional cost for icing inhibitor as long as the icing inhibitor concentration in the fuel pumped to the vessel is between 0.135 and 0.150 per cent.

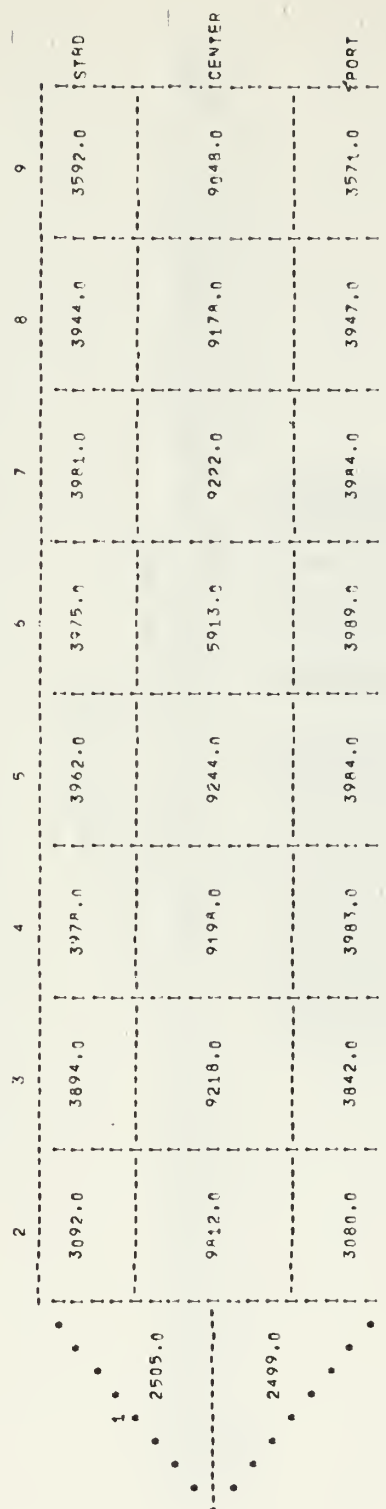
Even if the icing inhibitor concentration in the fuel pumped to the vessel must be greater than 0.150 per cent, it seems likely that increasing the icing inhibitor content in the fuel will be more economical than drying a vessel's tanks.



# A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A T-2 TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 136435.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 14.8
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.130 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.144 PERCENT MUST BE LOADED ABOARD THE VESSEL.

THE DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK.  
(BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF ICING INHIBITOR)



THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK AND THE RESULTING ICING INHIBITOR CONCENTRATION IN PERCENT BY VOLUME AFTER WATER EXTRACTION.



Figure 7a - A Simulation of Icing Inhibitor Concentrations in JP4 Aboard a T2 Tanker



# ECONOMIC ANALYSIS

COST TO DRY SHIP = \$ 168.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.144, SINCE THIS CONCENTRATION IS NOT ABOVE THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT. THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.139 PERCENT. NO YANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE SAVED.

IF DRYING TIME IS 4 HOURS, \$	672.	WILL BE SAVED.
IF DRYING TIME IS 8 HOURS, \$	1344.	WILL BE SAVED.
IF DRYING TIME IS 12 HOURS, \$	2016.	WILL BE SAVED.
IF DRYING TIME IS 16 HOURS, \$	2688.	WILL BE SAVED.
IF DRYING TIME IS 24 HOURS, \$	4032.	WILL BE SAVED.
IF DRYING TIME IS 36 HOURS, \$	6048.	WILL BE SAVED.
IF DRYING TIME IS 48 HOURS, \$	8064.	WILL BE SAVED.
IF DRYING TIME IS 60 HOURS, \$	10080.	WILL BE SAVED.
IF DRYING TIME IS 72 HOURS, \$	12096.	WILL BE SAVED.

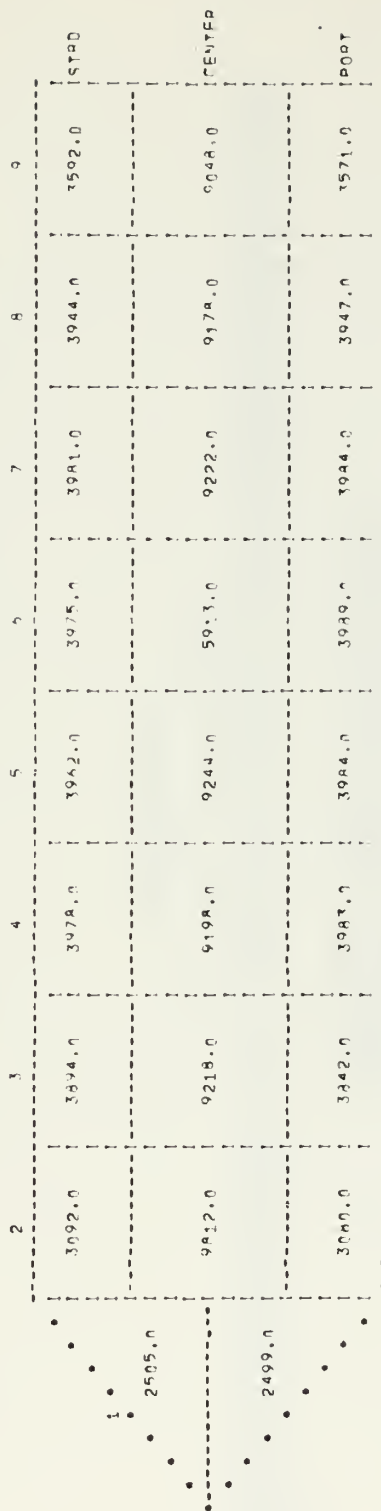
Figure 7b - Economic Analysis



A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A T-2 TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 136815.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DEY AS POSSIBLE = 14.8
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.137 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.142 PERCENT MUST BE LOADED ABOARD THE VESSEL.

THE DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK.  
(BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF ICING INHIBITOR)



THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK AND THE  
RESULTING ICING INHIBITOR CONCENTRATION IN PERCENT BY VOLUME AFTER WATER EXTRACTION.  
WATER ESTIMATE WAS 7.4 BARRELS.

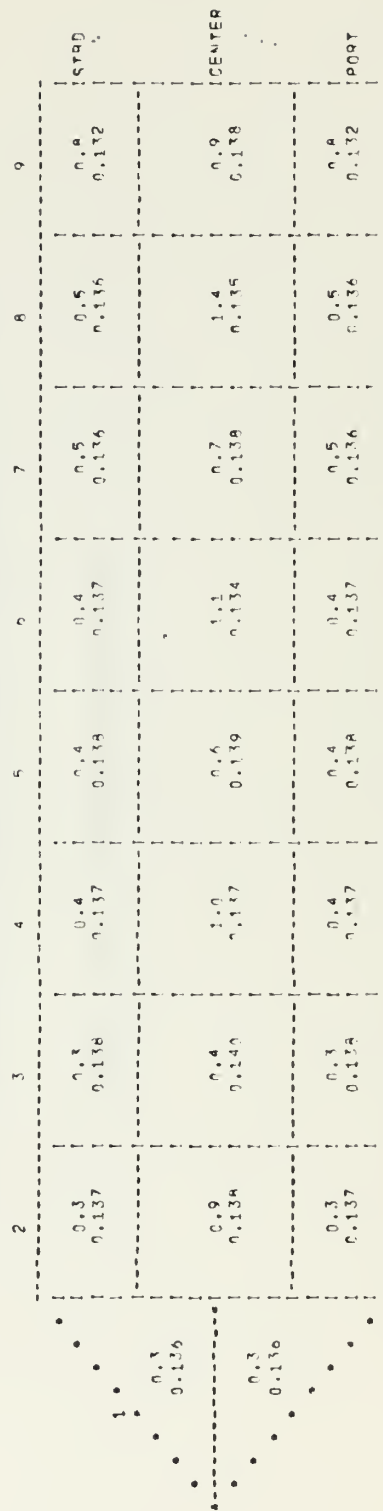


Figure 8a - A Simulation Using a Water Estimate of 50% Less Than Actual Water





# ECONOMIC ANALYSIS

COST TO RAY SHIP = \$ 168.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.142. SINCE THIS CONCENTRATION IS NOT ABOVE THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.17 PERCENT, NO TANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE SAVED.

IF DRYING TIME IS 4 HOURS, \$	672.	WILL BE SAVED.
IF DRYING TIME IS 8 HOURS, \$	1344.	WILL BE SAVED.
IF DRYING TIME IS 12 HOURS, \$	2016.	WILL BE SAVED.
IF DRYING TIME IS 16 HOURS, \$	2688.	WILL BE SAVED.
IF DRYING TIME IS 24 HOURS, \$	4032.	WILL BE SAVED.
IF DRYING TIME IS 36 HOURS, \$	6048.	WILL BE SAVED.
IF DRYING TIME IS 48 HOURS, \$	8064.	WILL BE SAVED.
IF DRYING TIME IS 60 HOURS, \$	10080.	WILL BE SAVED.
IF DRYING TIME IS 72 HOURS, \$	12096.	WILL BE SAVED.

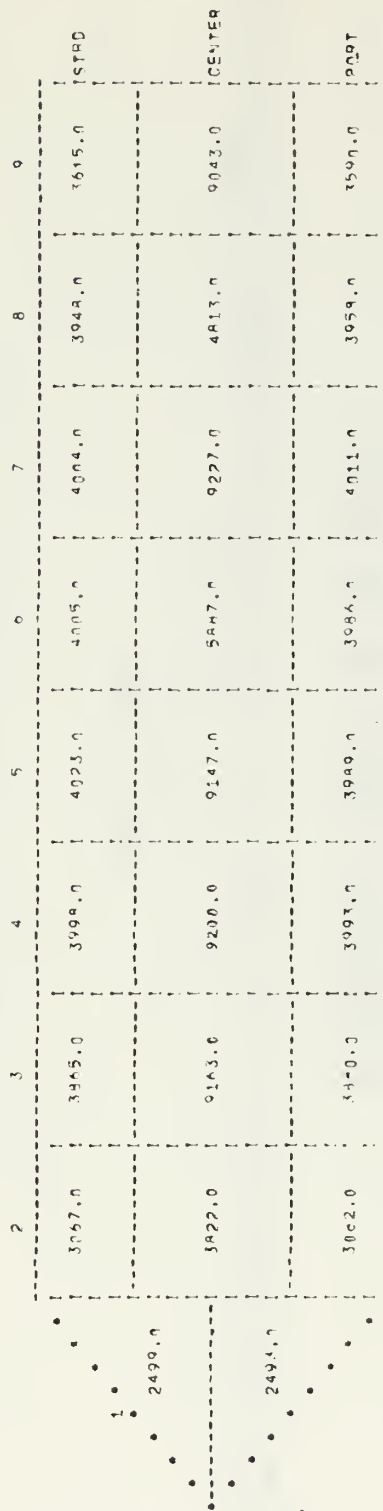
Figure 8b - Economic Analysis



A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN J04 ABOARD A T-2 TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 126109.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 14.8
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.140 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.146 PERCENT MUST BE LOADED ABOARD THE VESSEL.

THE DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK.  
(BARRELS OF PRODUCT EQUALS BARRELS OF J04 + BARRELS OF ICING INHIBITOR)



THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK AND THE  
RESULTING ICING INHIBITOR CONCENTRATION IN PERCENT BY VOLUME AFTER WATER EXTRACTION.  
WATER ESTIMATE WAS 22.2 BARRELS.

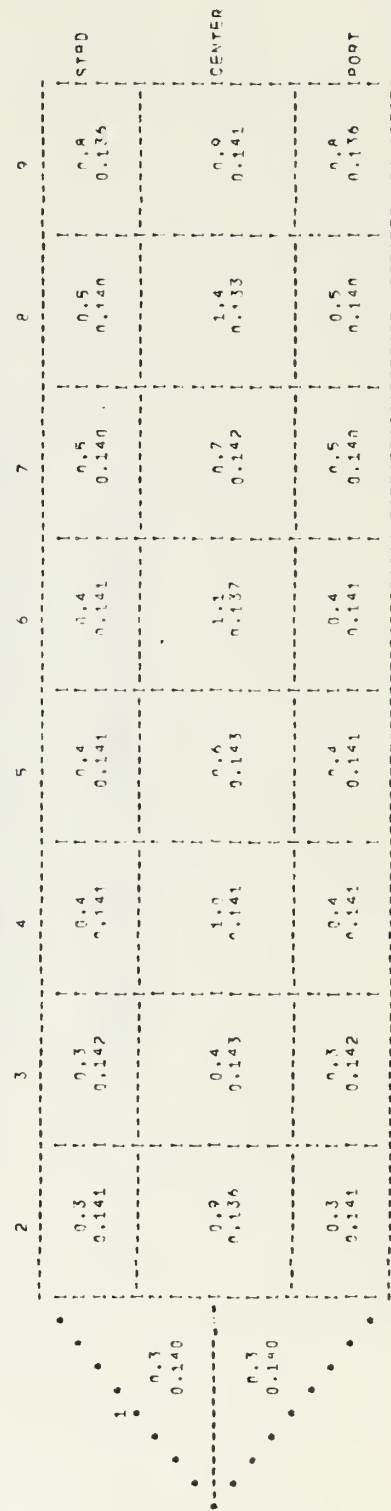


Figure 9a - A Simulation Using a Water Estimate of 50% More Than Actual Water



ECONOMIC ANALYSIS  
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COST TO DRY SHIP = \$ 168.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.14%. SINCE THIS CONCENTRATION IS NOT ABOVE THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.140 PERCENT. NO TANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE SAVED.

IF DRYING TIME IS 4 HOURS, \$	672.	WILL BE SAVED.
IF DRYING TIME IS 8 HOURS, \$	1344.	WILL BE SAVED.
IF DRYING TIME IS 12 HOURS, \$	2016.	WILL BE SAVED.
IF DRYING TIME IS 16 HOURS, \$	2688.	WILL BE SAVED.
IF DRYING TIME IS 24 HOURS, \$	4032.	WILL BE SAVED.
IF DRYING TIME IS 36 HOURS, \$	6048.	WILL BE SAVED.
IF DRYING TIME IS 48 HOURS, \$	8064.	WILL BE SAVED.
IF DRYING TIME IS 60 HOURS, \$	10080.	WILL BE SAVED.
IF DRYING TIME IS 72 HOURS, \$	12096.	WILL BE SAVED.

Figure 9b - Economic Analysis



A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A T-2 TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 126119.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 14.2
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.142 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.148 PERCENT MUST BE LOADED ABOARD THE VESSEL.

THE DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK.  
(BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF ICING INHIBITOR)

	2	3	4	5	6	7	8	9
1.	3067.0	3345.0	3098.0	4023.0	4005.2	4004.0	3048.0	3619.0
2.	3822.0	9163.0	9200.0	9147.0	5807.0	9227.0	4813.0	2043.0
3.	3062.0	3880.0	3093.0	3980.0	3066.0	4011.0	3058.0	3500.0
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THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK AND THE  
RESULTING ICING INHIBITOR CONCENTRATION IN PERCENT BY VOLUME AFTER WATER EXTRACTION.  
WATER ESTIMATE WAS 29.6 BARRELS.

	2	3	4	5	6	7	8	9
1.	0.3 0.143	0.3 0.144	0.4 0.142	0.4 0.143	0.4 0.143	0.5 0.141	0.5 0.142	0.8 0.138
2.	0.9 0.137	0.4 0.145	1.0 0.142	0.6 0.144	1.1 0.139	0.7 0.144	1.4 0.135	0.9 0.143
3.	0.3 0.143	0.3 0.144	0.4 0.142	0.4 0.143	0.4 0.143	0.5 0.141	0.5 0.142	0.8 0.137
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Figure 10a - A Simulation Using a Water Estimate of 100% More Than Actual Water





# ECONOMIC ANALYSIS

COST TO DRY SHIP = \$ 149.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.148. SINCE THIS CONCENTRATION IS NOT ABOVE THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.142 PERCENT. NO TANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE SAVED.

IF DRYING TIME IS 4 HOURS, \$ 672. WILL BE SAVED.  
 IF DRYING TIME IS 8 HOURS, \$ 1344. WILL BE SAVED.  
 IF DRYING TIME IS 12 HOURS, \$ 2016. WILL BE SAVED.  
 IF DRYING TIME IS 16 HOURS, \$ 2688. WILL BE SAVED.  
 IF DRYING TIME IS 24 HOURS, \$ 4032. WILL BE SAVED.  
 IF DRYING TIME IS 36 HOURS, \$ 6048. WILL BE SAVED.  
 IF DRYING TIME IS 48 HOURS, \$ 8064. WILL BE SAVED.  
 IF DRYING TIME IS 60 HOURS, \$ 10080. WILL BE SAVED.  
 IF DRYING TIME IS 72 HOURS, \$ 12096. WILL BE SAVED.

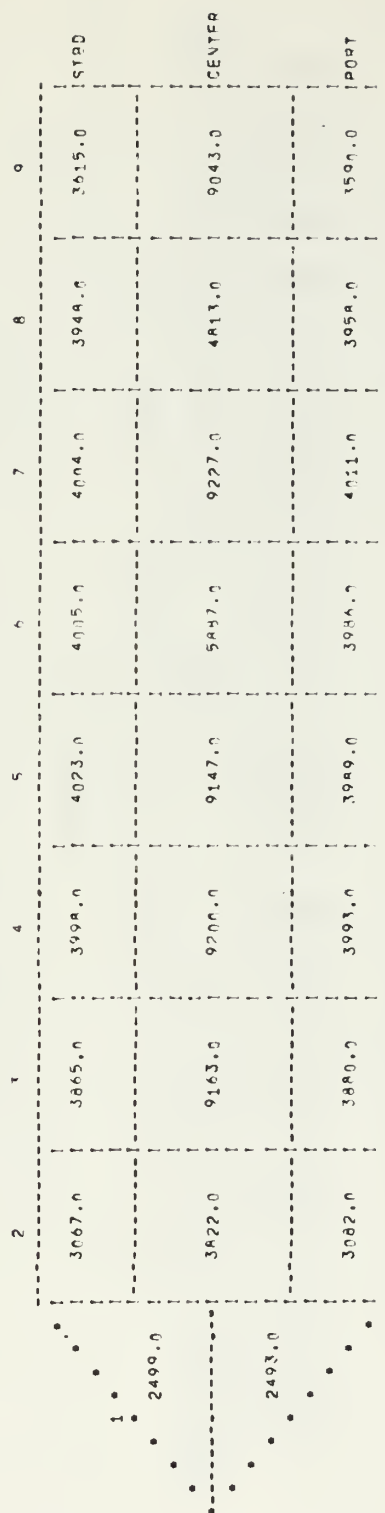
Figure 10b - Economic Analysis



# A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A T-2 TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.150 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 126304.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 8.4
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.149 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.153 PERCENT MUST BE LOADED ABOARD THE VESSEL.

THE DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK,  
(BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF ICING INHIBITOR)



THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK AND THE  
RESULTING ICING INHIBITOR CONCENTRATION IN PERCENT BY VOLUME AFTER WATER EXTRACTION.

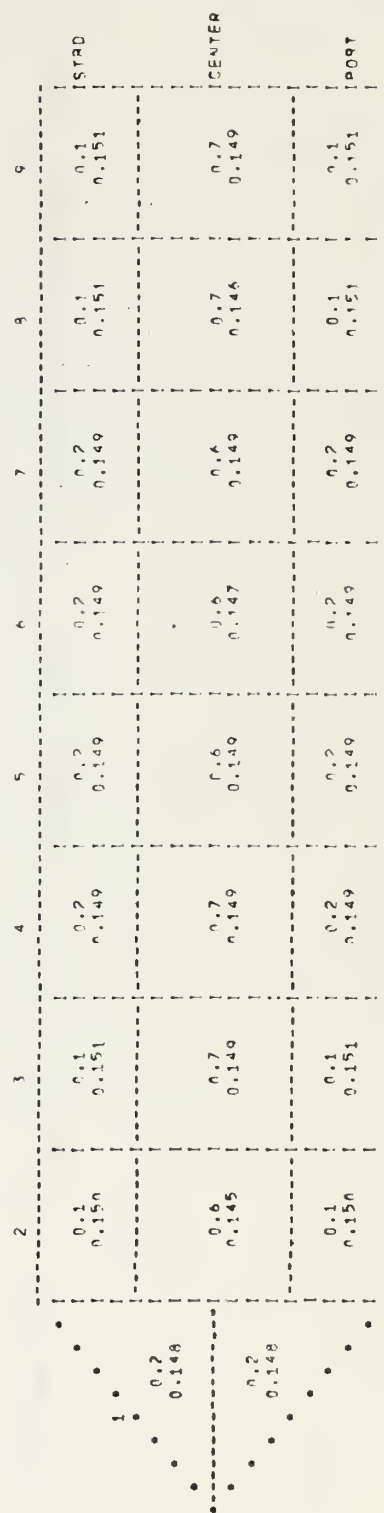


Figure 11a - Simulation Requiring an Additive Equilibrium Concentration of 0.15%



# ECONOMIC ANALYSIS

COST TO INCREASE ICING INHIBITOR CONCENTRATION OF THIS CARGO ABOVE 0.15 PERCENT = \$ 2121.97  
 COST TO DRY SHIP = \$ 168.00 PER HOUR.

IF DRYING TIME IS 4 HOURS, AN ADDITIONAL COST OF \$ 1450. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.  
 IF DRYING TIME IS 8 HOURS, AN ADDITIONAL COST OF \$ 778. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.  
 IF DRYING TIME IS 12 HOURS, AN ADDITIONAL COST OF \$ 106. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.  
 IF DRYING TIME IS 16 HOURS, \$ 566. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.  
 IF DRYING TIME IS 24 HOURS, \$ 1910. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.  
 IF DRYING TIME IS 36 HOURS, \$ 3926. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.  
 IF DRYING TIME IS 48 HOURS, \$ 5942. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.  
 IF DRYING TIME IS 60 HOURS, \$ 7958. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.  
 IF DRYING TIME IS 72 HOURS, \$ 9974. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.

IF DRYING TIME IS GREATER THAN 12.6 HOURS, IT WILL BE MORE ECONOMICAL TO ADD ADDITIONAL ICING INHIBITOR.

Figure 11b -- Economic Analysis Showing Effect of Additional Additive Cost



## CHAPTER VII

### A PROPOSED FIELD TEST

The results obtained in the various tests conducted in this thesis indicate that the method presented may someday be operational. The author is aware that even now, after a drying operation has been performed, some ships arrive at their destination with jet fuel not meeting the icing inhibitor specification. It is hoped that the information presented herein makes it clear that the additive is not lost through any means other than water contact. The great majority of vessels reach their destination with no additive loss, and it may be expected that a vessel loaded in the manner presented would experience no loss other than the loss accounted for.

A method to load a vessel will now be presented which the author considers feasible as an experiment to determine if any problems not considered thus far will arise when the thesis method is practically applied. The following assumptions will be made.

1. The gross quantity of barrels to be loaded aboard the vessel is known within 500 barrels. Let us assume 138,300 gross barrels will be loaded.
2. It is assumed that the refinery has facilities to line blend the icing inhibitor into the fuel while loading, in any quantity desired.





3. The average desired icing inhibitor content of the total cargo at equilibrium is 0.14 per cent.
4. The fuel temperature is in the range of 70-80°F.  
By using Table 7, the average amount of additive which will be absorbed by water aboard the vessel is determined as 31 per cent.

The percentages used in Table 7 were selected from the graph in Chapter III, page 21, and adjusted slightly after running computer simulations to determine the most desirable value.

TABLE 7  
ADDITIVE EQUILIBRIUM CONCENTRATIONS IN  
FUEL AND SEA WATER

<u>Desired Additive Content in Fuel at Equilibrium</u>	<u>Additive Content in Water Bottoms at Equilibrium</u>
<u>Per Cent</u>	<u>Per Cent</u>
0.15	33.5
0.14	31.0
0.13	29.5
0.12	26.5
0.11	24.5
0.10	22.0

After the vessel arrives at the dock and has completed discharging ballast, a visual estimate of the water remaining in each tank should be made. Let us assume that a



total of 966 gallons are estimated to remain. This quantity when converted to barrels equals 23.0. The following calculations must be performed.

1. Determination of additive quantity which will be absorbed by remaining ballast:

$$0.31 \times 23.0 = 7.13 \text{ barrels of additive}$$

2. Determination of additive quantity required for 0.14 per cent concentration after equilibrium:

$$138,300 \times 0.0014 = 193.6 \text{ barrels of additive}$$

3. Determination of additive percentage to be injected into fuel loaded aboard the vessel.

$$\frac{(193.6 + 7.13)100}{138,300} = \frac{20073}{138,300} = 0.145 \text{ per cent}$$

After loading is commenced, the shore loading line should be checked approximately every hour in order to determine that product containing 0.145 per cent additive is being loaded. The ship should be sampled frequently. It is possible that low additive concentrations will be experienced until a large quantity of fuel has been pumped aboard the vessel. After loading has been completed, average samples should be taken from each ship's tank and a composite sample should be made from these. The composite sample should test between 0.145 and 0.140 per cent additive. Until sufficient data has been accumulated to insure that the additive concentration is relatively uniform throughout the ship, each individual tank sample should be tested for additive concentration.



When the vessel arrives at the discharge port, the water bottoms in each ship's tank could be pumped into the receiving shore tank with the fuel and the water drained off, or the water bottoms in each tank aboard the vessel could be stripped into a shore slop tank prior to discharging the fuel.



## CHAPTER VIII

### CONCLUSIONS AND RECOMMENDATIONS

1. It would be economically desirable to use the proposed method since in most cases the additive concentration in the fuel loaded aboard the vessel need not contain any more icing inhibitor than is required by the military specification. In this case, assuming that the average tanker drying time is 12 hours and the average cost to operate a tanker is \$168.00 per hour, an annual savings of over 4,000 hours in tanker turn-a-round would result in addition to a savings of approximately \$700,000 in drying time. It is recommended, therefore, that field tests be conducted to determine if the method can be practically adopted.
2. Even though the additive concentration in fuel at equilibrium is different in each ship's tank, it does not vary sufficiently to restrict any portion of the cargo from being discharged in a multiple port discharge situation.
3. The additive equilibrium concentrations in known volumes of fuel and sea water may be predicted mathematically from available partitioning coefficients if the initial additive concentration in the fuel is known.
4. A partitioning coefficient of 220 may be used to determine mathematically additive concentrations at equilibrium if





the fuel is in the 70-80°F temperature range. In order to be as accurate as possible, the coefficient corresponding to the temperature of the fuel should be used. This coefficient may be determined from Figure 5, Chapter III. Further study of actual additive concentrations in fuel and sea water versus mathematical predictions at varying temperatures would be desirable.

5. The time required for equilibrium to be established aboard a vessel must be determined by field test. Even though the time required for equilibrium is not known, the range in which the additive concentration should be upon completion of loading is known. The additive concentration of the ship's composite sample after completion of loading will indicate whether or not the additive concentration at equilibrium will be within specification limits.
6. The small quantity of salt water remaining aboard the vessel will not significantly affect the quality of the fuel.



## REFERENCES

- <sup>1</sup>W. C. French and E. A. Malick. Jet Fuel Anti-Icing Additives-A New Concept in Safety of Flight. Society of Automotive Engineers, Paper 356B, New York, 1961, p. 1.
- <sup>2</sup>Defense Fuel Supply Center, Washington, D. C., phone conversation with Procurement Branch, December, 1967.
- <sup>3</sup>Bureau of Naval Personnel. Fundamentals of Petroleum (Washington, D. C.: Bureau of Naval Personnel, 1965), p. 153.
- <sup>4</sup>Letter from C. C. Dusek, Captain, U. S. N., Military Sea Transportation Service, Washington, D. C., Sept. 28, 1967.
- <sup>5</sup>Bureau of Naval Personnel. op. cit., p. 143.
- <sup>6</sup>Phillips Petroleum Company. PFA 55MB Fuel Additive (Bartlesville, Oklahoma: Phillips Petroleum Company, 1964), p. 5.
- <sup>7</sup>Frank H. MacDougall. Physical Chemistry (New York: The Macmillan Company, 1949), p. 349.
- <sup>8</sup>R. E. Linnard. Phillips Petroleum Company, Bartlesville, Oklahoma, personal interview, November, 1967.
- <sup>9</sup>Phillips Petroleum Company. op. cit., p. 6.
- <sup>10</sup>R. E. Linnard. op. cit.
- <sup>11</sup>Phillips Petroleum Company. op. cit., p. 19.
- <sup>12</sup>Ibid., pp. 14-15.
- <sup>13</sup>Defense Fuel Supply Center. Contract DSA-600-10692 (Washington, D. C.: Defense Fuel Supply Center, 1966), p. 6.



## APPENDIXES



APPENDIX A

MILITARY SPECIFICATION TURBINE FUEL, AVIATION,  
GRADES JP-4 and JP-5 (MIL-T-5624G)





MIL-T-5624G  
5 NOVEMBER 1965

SUPERSEDING  
MIL-J-5624F  
25 September 1962

# MILITARY SPECIFICATION

## TURBINE FUEL, AVIATION, GRADES JP-4 AND JP-5

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

### 1. SCOPE

1.1 Scope.— This specification covers two grades of aviation turbine fuel (see 6.1).

1.2 Classification.— Aviation turbine fuel shall be of the following grades, as specified (see 6.2):

<u>Grade</u>	<u>NATO No.</u>	<u>Description</u>
JP-4	<u>F-40</u>	Wide-cut, gasoline type
JP-5	<u>F-44</u>	High flashpoint, kerosene type

### 2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

#### SPECIFICATIONS

##### Military

MIL-I-25017	Inhibitor, Corrosion, Fuel Soluble
MIL-I-27686	Inhibitor, Fuel System Icing

#### STANDARDS

##### Federal

Federal Test Method Std. No. 791	Lubricants, Liquid Fuels, and Related Products; Methods of Testing
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##### Military

MIL-STD-290	Packaging, Packing and Marking of Petroleum and Related Products
-------------	--

FSC 9130



MIL-T-5624G

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications.- The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

American Society for Testing and Materials Publications  
ASTM Standards Parts 17 and 18

(Copies of ASTM publications may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

### 3. REQUIREMENTS

3.1 Materials.- The fuel shall consist completely of hydrocarbon compounds, except as otherwise specified herein.

3.2 Chemical and physical requirements.- The chemical and physical requirements of the finished fuel shall conform to those listed in table I. Requirements contained herein are not subject to corrections for test tolerances. If multiple determinations are made, results falling within any specified repeatability and reproducibility tolerances may be averaged.

3.2.1 Water reaction.- In addition to the interface rating specified in table I, JP-4 fuel shall separate sharply from the water layer and there shall be no evidence of an emulsion or precipitate, within or upon either layer.

3.3 Additives.- The additives listed herein may be used singly or in combination in amounts not to exceed those specified. The type and amount of each additive used shall be reported (see 6.3).

3.3.1 Antioxidants.- The following active inhibitors may be blended separately or in combination into the fuel in total concentration not in excess of 8.4 pounds of inhibitor (not including weight of solvent) per 1,000 barrels of fuel (9.1 gm./100 gal. (U.S.), 24 mg./liter or 109 mg./gal.(U.K.)) in order to prevent the formation of gum:

- (a) N,N' - diisopropyl-para-phenylenediamine
- (b) N,N' - disecundary butyl-para-phenylenediamine
- (c) 2,6-ditertiary butyl-4-methylphenol
- (d) 2,4-dimethyl-6-tertiary butylphenol
- (e) 2,6-ditertiary butylphenol
- (f) 75 percent min. 2,6-ditertiary butylphenol  
25 percent max. tertiary and tritertiary butylphenols



MIL-T-5624G

TABLE I. Chemical and physical requirements and test methods

Requirements	Fuel		Test method	
	Grade JP-4 NATO No. F-40	Grade JP-5 NATO No. F-44	Fed. Test Method Std. No. 791	ASTM standards
Distillation:				
Initial boiling point	1/ 1/	1/ 400° F (204.4° C)		
Fuel evaporated, 10 percent min. at				
Fuel evaporated, 20 percent min. at	290° F (143.3° C)	1/ (204.4° C)		
Fuel evaporated, 50 percent min. at	370° F (187.8° C)	1/		
Fuel evaporated, 90 percent min. at	470° F (243.3° C)	1/	1001	D86 2/
End point, max.	1/ 1-1/2	550° F (287.8° C)		
Percent evaporated, at 400° F (204.4° C)	1-1/2	1-1/2		
Residue, vol. percent max.	1-1/2	1-1/2		
Distillation loss, vol. percent max.	45.0 (0.802)	36.0 (0.845)	401	D287
Gravity °API - min. (sp. gr. max.)	57.0 (0.751)	48.0 (0.788)	401	D381
Gravity °API - max. (sp. gr. min.)	7	7	3302	
Existent gum, mg./100 ml. max.				
Total potential residue, 16 hour aging, mg./100 ml. max.	14	14	3354	D873
Sulfur, total, percent weight max.	0.4	0.4	5201	D1266
Mercaptan sulfur, percent weight max. 3/	0.001	0.001	5204	D1219 or D1323
Reid vapor pressure, 100° F, psi, min., (gm./cm. <sup>2</sup> , min.)	2.0 (140.6)	----	1201	D323
Reid vapor pressure, 100° F, psi, max., (gm./cm. <sup>2</sup> , max.)	3.0 (210.9)	----	1201	D323
Freezing point, max.	-72° F (-58° C)	-51° F (-46° C)	1411	D2386
Heating value:				
Net heat of combustion, Btu/lb., min., or aniline-gravity product, min. 4/	18,400 5,250	18,300 4,500	2502 3601 and 401	D246 D611 and D287
Viscosity, centistokes at -30° F (-34.4° C); max.	----	16.5	305	D445
Aromatics, vol. percent max.	25.0	25.0	3703	D1319
Olefin, vol. percent max.	5.0	5.0	3703	D1319

See footnotes at end of table



MIL-T-5624G

TABLE I. Chemical and physical requirements and test methods (continued)

Requirements	Fuel			Test method	
	Grade JP-4 NATO No. F-40	Grade JP-5 NATO No. F-44	Fed. Test Method Std. No. 791	ASTM standards	
Smoke point, mm. min. or luminometer No., min. Explosiveness, percent max. Flash point, min.	----- ----- ----- -----	19.0 50 50 140° F (60.0° C)	2107 2108 1151 1102	D1322 D1740 ----- D93	
Smoke volatility index, min. or luminometer No., min.	52.0 5/ 60	-----	-----	-----	
Copper strip corrosion, ASTM classification max.	No. 1	No. 1	2108	D1740	
Water separator index, min.	85	85	5325	D130 6/	
Water reaction, interface rating, max.	1b.	-----	3256	-----	
Thermal stability: Change in pressure drop in 5 hours, in. of Hg, max. Preheater deposit less than Particulate matter, mg./gal. max. F.O.B. origin deliveries mg./gal. max. F.O.B. destination deliveries Fuel system icing inhibitor, percent vol., max.	3 3 4 8 0.15	3 3 ----- ----- -----	3464 7/ ----- ----- 3008 3008 5327 or 5340 5327 or 5340	D1660 7/ ----- ----- D2276 D2276 ----- ----- -----	
Fuel system icing inhibitor, percent vol., min.	0.10	-----	-----	-----	

1/ To be reported-not limited.

2/ A condenser temperature of 32° to 40° F shall be used for the distillation of grade JP-5. For JP-4, use group 3 test conditions.

3/ The mercaptan sulfur determination may be waived at the option of the inspector if the fuel is "doctor sweet" when tested in accordance with Method 5203 of Federal Test Method Standard No. 791.

4/ Aniline-gravity product is defined as the product of the gravity in °API and the aniline point in ° F.

5/ The smoke volatility index (SVI) is the smoke point (SP) + (0.42 X volume percent boiling under 400° F (204.4° C)).

6/ To be performed in accordance with paragraph titled, "Tests at 212° F (100° C) volatile materials" of ASTM D130-56.

7/ See (4.6.1) for test conditions.





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3.3.2 Metal deactivator.- A metal deactivator, N, N'-disalicylidene-1, 2 propane-diamine may be blended into the fuel in an amount not to exceed 2 pounds of active ingredient per 1,000 barrels of fuel (2.2 gm./100 gal. (U.S.), 5.8 mg./liter or 25 mg./gal. (U.K.)).

3.3.3 Corrosion inhibitor.- A corrosion inhibitor shall not be added to grade JP-4 or JP-5 fuel by the supplier or the transporting agency unless prior approval is obtained from the procuring agency. When used, the corrosion inhibitor shall conform to MIL-I-25017 and the finished fuel shall meet all the requirements specified in section 3. No limit is placed on the minimum amount which may be added. The maximum allowable concentration shall not exceed that listed in the latest revision of QPL-25017. If a corrosion inhibitor is used, the contractor or transporting activity, or both, shall maintain and upon request, make available to the Government, evidence that the corrosion inhibitors used are equal in every respect to the product specified in MIL-I-25017.

3.3.4 Fuel system icing inhibitor.- The fuel system icing inhibitor shall conform to MIL-I-27686.

3.4 Workmanship.- The finished fuel shall be visually free from undissolved water, sediment or suspended matter and shall be clean and bright at the ambient temperature or at 70° F, whichever is higher.

#### 4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection.- Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of tests.- For acceptance purposes, individual lots shall be subjected to all tests and other requirements cited in section 3.

##### 4.3 Inspection lot.-

4.3.1 Bulk lot.- An indefinite quantity of a homogeneous mixture of material offered for acceptance in a single isolated container.

4.3.2 Packaged lot. - An indefinite number of 55-gallon drums or smaller unit packages of identical size and shape offered for acceptance and filled from one isolated tank containing a homogeneous mixture of material.

4.4 Sampling.- Each bulk or packaged lot of material shall be sampled for verification of product quality and compliance with MIL-STD-290 as applicable, in accordance with Method 8001 of Federal Test Method Standard No. 791 (ASTM D270).



MIL-T-5624G

4.5 Inspection.- Inspection shall be in accordance with Method 9601 of Federal Test Method Standard No. 791.

4.6 Test methods.- Tests, to determine conformance to chemical and physical requirements, shall be conducted in accordance with Federal Test Method Standard No. 791 or ASTM standards, using the applicable methods as listed in table I, except for the following.

4.6.1 Thermal stability.- The thermal stability test shall be conducted using a preheater temperature of 300° F, a filter temperature of 400° F, a fuel flow of 6 pounds per hour over a test period of 300 minutes.

4.6.1.1 Reported data.- The following data shall be reported:

- (a) Differential pressure in inches of mercury at 300 minutes, or time to a differential pressure of 3 inches of mercury, whichever comes first.
- (b) Preheater deposit code rating at the end of the test.

## 5. PREPARATION FOR DELIVERY

5.1 Packaging, packing, and marking.- Packaging, packing and marking shall be in accordance with MIL-STD-290.

## 6. NOTES

6.1 Intended use.- The fuel covered by this specification is intended for use in aircraft turbine engines, ramjet engines, and rocket engines.

6.2 Ordering data.- Procurement documents should specify:

- (a) Title, number, and date of this specification.
- (b) Grade of fuel required (see 1.2).
- (c) Quantity required and size containers desired.
- (d) Level of packaging and packing required (see 5.1).

6.3 Precaution for mixing inhibitors.- To prevent any possible reaction between the concentrated forms of different inhibitors (see 3.3), the fuel supplier is cautioned not to commingle inhibitors prior to their addition to the fuels.

6.4 International agreements.- Certain provisions of this specification are the subject of international standardization agreement (ASCC 15/1- STANAG No. 1135). When amendment, revision, or cancellation of this specification is proposed, the departmental custodians will inform their respective Departmental Standardization Offices so that appropriate action may be taken respecting the international agreement concerned.



MIL-T-5624G

## Custodians:

Army - MR  
Navy - WP  
Air Force - (11)

## Preparing activity:

Air Force - (11)

Project No. 9130-0017

## Reviewer activities:

Army - MR  
Navy - WP  
Air Force - (11), (68)

## User activities:

Army - MI, MO  
Navy -  
Air Force -

International interest (see 6.4)



APPENDIX B  
MILITARY SPECIFICATION, INHIBITOR, FUEL SYSTEM ICING  
(MIL-I-27686D and Amendment 1)





MIL-I-27686D

17 SEPTEMBER 1964

SUPERSEDING

MIL-I-0027686C (USAF)

16 AUGUST 1963

MIL-I-27686B

11 FEBRUARY 1963

## MILITARY SPECIFICATION

### INHIBITOR, FUEL SYSTEM ICING

*This specification has been approved by the Department of Defense and is mandatory for use by the Departments of the Army, the Navy, and the Air Force.*

#### 1. SCOPE

1.1 This specification covers one type and grade of inhibitor, anti-icing, soluble in jet turbine fuels.

#### 2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

##### STANDARDS

###### FEDERAL

Fed. Test Method Std. No. 141—Paint, Varnish, Lacquer, and Related Materials; Methods of Inspection, Sampling, and Testing.

Fed. Test Method Std. No. 791—Lubricants, Liquid Fuels, and Related Products; Methods of Testing.

###### MILITARY

MIL-STD-105—Sampling Procedures and Tables for Inspection by Attributes.

MIL-STD-290—Packaging, Packing and Marking of Petroleum and Related Products.

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply:

##### AMERICAN SOCIETY FOR TESTING AND MATERIALS PUBLICATIONS

E70-52T—Determination of pH of Aqueous Solutions with the Glass Electrode.

D891—Tests for Specific Gravity of Industrial Aromatic Hydrocarbons and Related Materials.

D1078—Test for Distillation Range of Lacquer Solvents and Diluents.

D1209—Test of Color of Clear Liquids.

D1218—Measurement of Refractive Index and Refractive Dispersion of Hydrocarbon Liquids.

D1364—Test for Water in Lacquer Solvents and Diluents.

D1613-61T—Test for Acidity in Lacquer Solvents and Diluents.

(Copies of ASTM publications may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa., 19103.)

#### 3. REQUIREMENTS

3.1 Materials. The ingredient materials used in the manufacture of the inhibitor shall conform to the requirements specified herein.

3.1.1 *Certification.* The manufacturer shall certify that the ingredient materials have been included in the proportions specified in 3.2.

3.2 Composition. The composition of the inhibitor shall be as specified in table I.

TABLE I. Composition

Ingredient material	Percent (by weight)
Ethylene glycol monomethyl ether.....	99.6 ± 0.04
Glycerol.....	0.4 ± 0.04

FSC 6850



## MIL-I-27686D

**3.2.1 Properties.** The ethylene glycol monomethyl ether ingredient shall have the properties specified in table II.

**3.2.2 Glycerol.** The glycerol ingredient shall have the properties specified in table III.

**3.3 Properties of the compounded inhibitor.** The compounded inhibitor shall conform to the requirements specified in table IV.

TABLE II. *Properties of ethylene glycol monomethyl ether ingredient*

Property	Requirement
Acid number, mg. KOH per gram (maximum).	0.09
Color, platinum cobalt (maximum).	15
Distillation:	
Initial point (minimum).....	123.5° C
Dry point (maximum).....	125.5° C
Ethylene glycol (maximum).....	0.025 weight percent
Specific gravity (20°/20° C).....	0.963 to 0.967

TABLE III. *Properties of glycerol ingredient*

Property	Requirement
Acid number, mg. KOH per gram (maximum).	0.09
Color, platinum cobalt (maximum).	20
pH of 25% solution in water (25° ± 2° C).	6.0 to 7.0
Specific gravity (20°/20° C).....	1.2623 to 1.2636
Water, percent by weight (maximum).	0.5

TABLE IV. *Properties of the compounded inhibitor*

Property	Requirement
Acid number, mg. KOH per gram (maximum).	0.09
Color, platinum cobalt (maximum).	20
Glycerol.....	0.36 to 0.44 weight percent
pH of 25% solution in water (25° ± 2° C).	6.0 to 7.0
Refractive index (25° C).....	1.4000 to 1.4010
Specific gravity (20°/20° C).....	0.965 to 0.969
Water (maximum).....	0.2 weight percent

**3.4 Workmanship.** The ingredient materials shall be assembled and processed in accordance with high-grade commercial practice to produce

an inhibitor uniform in quality and free from suspended and foreign matter (see 4.5.1).

#### 4. QUALITY ASSURANCE PROVISIONS

**4.1 Responsibility for inspection.** Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any other commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

**4.2 General inspection provisions.** Except where otherwise indicated, the provisions of this section are applicable to the compounded inhibitor. The quality assurance of ingredient materials covered by applicable specifications shall be in accordance with such specifications. Sampling and inspection of ingredient materials not covered by separate specifications shall be as specified herein. Unless otherwise specified, general inspection provisions shall be in accordance with Method 9601 of Federal Test Method Standard No. 791.

#### 4.3 Sampling.

**4.3.1 Sampling of ingredient materials.** The ethylene glycol monomethyl ether and glycerol ingredient materials shall be sampled in accordance with Method 8001 of Federal Test Method Standard No. 791. Samples selected for ethylene glycol monomethyl ether shall be subjected to the tests for acid number, color, distillation, ethylene glycol (percent), and specific gravity as specified in 4.6.1 through 4.6.1.1.3. Samples selected for glycerol shall be subjected to the tests for acid number, color, specific gravity, water, glycerol (percent by weight) and pH of 25 percent solution in water as specified in 4.6.1, 4.6.1.2, and 4.6.1.3. Sampling and testing of the ingredient materials shall be conducted prior to compounding.

**4.3.2 Sampling of product.** The inhibitor shall be sampled in accordance with Method 8001 of Federal Test Method Standard No. 791. The samples shall be subjected to the examination of product and all tests specified under 4.6, with the exception of the test for



## MIL-I-27686D

ethylene glycol (percent by weight) (see 4.6.1.1).

**4.3.3 Sampling for inspection of filled containers.** A random sample of filled containers shall be selected from each lot, in accordance with Standard MIL-STD-105, inspection level I, AQL of 2.5 percent defective. The sample containers shall be subjected to the examination of filled containers as specified in 4.5.2.

**4.4 Report of tests.** The manufacturer shall submit test reports to the procuring activity showing the results of all tests specified herein. The report shall be accompanied by the certification of ingredients as required in 3.1.1.

#### 4.5 Examinations.

**4.5.1 Examination of product.** Samples selected in accordance with 4.3.2 shall be visually examined for compliance with 3.4.

**4.5.2 Examination of filled containers.** Each container selected as specified in 4.3.3 shall be examined for defects of the container and closure, for evidence of leakage, for unsatisfactory markings and all other preparation for delivery requirements. Each filled container shall also be weighed to determine the amount of contents. Any container in the sample having one or more defects or under required fill shall be rejected.

**4.5.3 Examination of empty containers.** Containers shall not contain any foreign material, such as solids, corrosion products, water, or other sediments. Container seams shall be inspected for evidence of metal erosion, flux, solder, and such materials as would contaminate the product. Any container not meeting these criteria shall be rejected.

#### 4.6 Test methods.

**4.6.1 The inhibitor and its ingredient materials** shall be tested in accordance with test methods listed in table V and other methods as described in 4.6.1.1, 4.6.1.2, and 4.6.1.3.

**4.6.1.1 Ethylene glycol (percent by weight).** The percent of ethylene glycol in the ethylene glycol monomethyl ether component shall be determined as specified in the following subparagraphs.

**4.6.1.1.1 Reagents and materials.** Unless otherwise indicated, all reagents shall be American Chemical Society reagent grade, or equivalent. References to water indicate dis-

TABLE V. Test methods

Test	ASTM Method No.
Acid number.....	D1613-61T
Color.....	D1209
Distillation.....	D1078
Refractive index.....	D1218
Specific gravity.....	D891 (Method C)
Water.....	D1361

tilled or deionized water. The following materials shall be prepared:

- (a) Oxidizing reagents: To a solution of 5 grains (g.) of periodic acid ( $\text{HIO}_4$ ) in 200 milliliters (ml.) of water, add 800 ml. of glacial acetic acid. Store the solution in a dark, well-stoppered bottle.
- (b) Potassium iodide: Twenty percent aqueous solution.
- (c) Sodium thiosulfate, standard 0.1 N: Standardize by an accepted procedure.
- (d) Starch indicator solution: One percent aqueous.

**4.6.1.1.2 Procedure.** The following procedure shall be performed:

- (a) Pipette 50 ml. of the oxidizing reagent into each of four 500-ml. iodine flasks. Reserve two of the flasks for the blank determination.
- (b) Introduce 50 g. of the sample, weighed to the nearest 0.1 g., into each of two flasks and swirl to effect solution.
- (c) Allow the flasks to stand for 30 minutes at room temperature.
- (d) While swirling, add 10 ml. of 20-percent potassium iodide solution to each flask in turn immediately before titrating.
- (e) Titrate the contents of each flask to a pale yellow color with standard 0.1 N sodium thiosulfate. Add 1 ml. of starch indicator and titrate to the disappearance of the blue color.
- (f) If the net titration is more than 20 ml., repeat the determination, using a smaller sample size.

**4.6.1.1.3 Calculations.** Calculate the concentration of ethylene glycol as:

Weight percent ethylene glycol

$$= \frac{(B-A)(N)(3.103)}{(S)}$$





## MIL-I-27686D

Where A=ml. of sodium thiosulfate required for the sample

B=average ml. of sodium thiosulfate required for the blank

N=normality of sodium thiosulfate

S=grams of sample.

**4.6.1.2 Glycerol (percent by weight).** The procedure shall be as specified in 4.6.1.1.2, except the sample size shall weigh 10 g. to the nearest 0.1 milligram.

**4.6.1.2.1 Calculations.** Calculate the concentration of glycerol as:

$$\text{Weight percent glycerol} = \frac{(B-A)(N)(2.302)}{S}$$

Where A=ml. of sodium thiosulfate required for the sample

B=average ml. of sodium thiosulfate required for the blank

N=normality of sodium thiosulfate

S=weight of sample (gram).

**4.6.1.3 pH of 25 percent solution in water.** Twenty-five ml. of the inhibitor shall be pipetted into a 100-ml. volumetric flask and filled with freshly boiled and cooled distilled water having a pH of 6.5 to 7.5. The pH value shall be measured with a pH meter calibrated in accordance with ASTM Method E70-52T.

## 5. PREPARATION FOR DELIVERY

**5.1 Packaging, packing, and marking.** The packaging, packing, and marking shall be in accordance with Standard MIL-STD-290. The shipment marking nomenclature shall be: INHIBITOR, FUEL SYSTEM ICING.

**5.1.1 Precautionary markings.** In addition to the markings required by 5.1, each container shall be marked with the following precautionary marking:

TO BE USED ONLY AS AN ANTI-ICING  
ADDITIVE FOR JET TURBINE EN-  
GINE FUELS.

## 6. NOTES

**6.1 Intended use.** The inhibitor is intended for use as an anti-icing agent to be added to jet turbine engine fuels.

**6.2 Ordering data.** Procurement documents should specify:

(a) Title, number, and date of this specification.

(b) Responsibility for inspection records, if other than supplier (see 4.1).

(c) Applicable levels of packaging and packing (see 5.1).

**6.2.1 Unit of purchase.** Unit of purchase is the U.S. gallon of 231 cubic inches at 15.5° C (60° F).

**6.3 International standardization.** Certain provisions of this specification are the subject of international standardization agreement ABC AIR STD 15/1 and STANAG 3437. When amendment, revision, or cancellation of this specification is proposed, the departmental custodians will inform their respective Departmental Standardization Offices so that appropriate action may be taken respecting the international agreement concerned.

**6.4 Marginal indicia.** The margins of this specification are marked to indicate where changes, deletions, or additions to the previous issue have been made. This is done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Figures are not so marked. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content as written, irrespective of the marginal notations and relationship to the last previous issue.

### Custodians:

Army—MU

Navy—Weps

Air Force—ASD (11)

International interest (see 6.3)

### Reviewer activity:

Army—

Navy—Weps

Air Force—ASD (11)

### User activity:

Army—

Navy—

Air Force—

### Preparing activity:

Air Force—ASD (11)

Project No. 6850-0132

Review/user information is current as of the date of this document. For future coordination of changes to this document, draft circulation should be based on the information in the current Federal Supply Classification Listing of DoD Standardization Documents.





MIL-I-27686D  
AMENDMENT - 1  
6 SEPTEMBER 1966

## MILITARY SPECIFICATION

## INHIBITOR, FUEL SYSTEM ICING

This amendment forms a part of Military Specification MIL-I-27686D, 17 September 1964, and is mandatory for use by all Departments and Agencies of the Department of Defense.

Page 1: Add as new paragraph:

"1.2 Classification. - The NATO symbol for this material is as follows:

S-748 "

Page 2, table II: Add the following as last two items of table:

<u>Property</u>	<u>Requirement</u>
"pH of 25% solution in water (25° +2° C)	6.0 to 7.0
Water, percent by weight (maximum)	0.15".

Page 4, paragraph 6.3, fourth line: Delete "STANAG 3437" and substitute "STANAG 1135"

## Custodians:

Army - MU  
Navy - AS  
Air Force - (11)

Preparing activity:  
Air Force - (11)

Project No. 6850-0288

## Reviewer activities:

Army - MU  
Navy - AS  
Air Force - (11), (68)

FSC 6850



APPENDIX C  
DETERMINATION OF FUEL SYSTEM ICING  
INHIBITOR IN HYDROCARBON FUELS  
(Federal Test Method 5340)



## DETERMINATION OF FUEL SYSTEM ICING INHIBITOR IN HYDROCARBON FUELS (Refractometer Method)

### 1. SCOPE

1.1 This method is used for the determination of 0.05 to 0.20 volume percent ethylene glycol monomethyl ether,  $\text{CH}_3\text{O}(\text{CH}_2)_2\text{OH}$ , and glycerine,  $\text{CHOH}(\text{CH}_2\text{OH})_2$  as icing inhibitor in turbine fuels. Refer to Mil. Spec. MIL-I-27686 for details on fuel system icing inhibitor. The test consists of removing the ethylene glycol monomethyl ether and glycerin from the hydrocarbon fuel by extraction with water. The amount of icing inhibitor in the extract is determined by measuring the difference between its refractive index and that of the water used in making the extraction.

### 2. SPECIMEN

2.1 Eight hundred ml. of hydrocarbon fuel.

### 3. APPARATUS

3.1 Portable differential refractometer kit. The kit includes the differential refractometer and all other equipment necessary to perform the evaluation. All items except the differential refractometer are standard laboratory items available from supply house.

Note 1. The kit used in this test method is available from the Seiscor Products Section, Seismograph Service Corp., P.O. Box 1590, Tulsa, Oklahoma. It contains, in addition to the refractometer, a built in ring stand, a one-liter separatory funnel, a 200 ml. graduate, syringe and needle for cell cleaning, one polyethylene wash bottle, one polyethylene bottle for distilled water, one glass bottle, four glass vials, and a tube of stopeck grease. All the above are housed in a luggage type case.

### 4. MATERIALS

4.1 Ethylene glycol monomethyl ether-glycerin standard solution for calibration of instrument. (These solutions should be made in a laboratory where necessary equipment is available). Pipet 8.0 ml. of ethylene glycol monomethyl ether-glycerin solution into 500.0 ml. of distilled water (volumes must be accurate) and mix thoroughly. The final solution is equivalent to 0.10 volume percent of ethylene glycol monomethyl ether-glycerin in fuel. Repeat using 4.0, 12.0, and 16.0 ml. of ethylene glycol monomethyl ether-glycerin solution in the first step thereby making standard solutions of equivalent 0.05, 0.15, and 0.20 volume percent in fuel.

4.2 Distilled water.

4.3 Weak water-detergent solution consisting of 1 quart commercial liquid dishwashing detergent to 100 parts distilled water.

### 5. PROCEDURE

5.1 Preliminary steps in zeroing instrument. With light switch released, zero potentiometer with the screw located directly below the scale. Fill all the cells of the cell block with distilled water. Place cell block in light path and close cover. Zero the meter with the adjusting screw located near the upper right corner of the potentiometer. Clean and dry center cell of cell block. (Use weak detergent, rinse with distilled water, and dry with syringe and needle provided).

5.2 Calibration curve. This is prepared by determining differential refractive index measurements on the known solutions listed in 4.1, and plotting the vernier reading against the known amount of icing inhibitor. Once a curve has been prepared for a given-



**METHOD 5310****July 1, 1965**  

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cell and instrument, it can be used indefinitely. (If batteries are changed, or minor repairs made, checking of one point on the calibration curve should be sufficient. If the cell block is replaced, a new calibration curve should be drawn).

**5.3 Extraction of hydrocarbon fuel.**

Measure 800 ml. of hydrocarbon fuel to be tested, into a one-liter separatory funnel. Measure 50 ml. of distilled water into the fuel in the one-liter separatory funnel. Shake the separatory funnel vigorously by hand for three minutes. Place the funnel in a ring holder so that the layers may separate. Then draw off most of the water layer into a previously cleaned and dried two-ounce bottle. **TAKE CARE NOT TO DRAW OFF ANY OF THE HYDROCARBON LAYER.**

**5.4 Differential refractive index measurement.** Using the syringe and special needle supplied, rinse the center cell three times with the extract. Place cell block in the refractometer. Depress the light switch located near the left front corner of the instrument. Zero the potentiometer by rotating the vernier scale. Note reading on vernier scale and apply to calibration curve to obtain volume percent anti-icing additive in the sample of fuel.

**6. PRECISION**

**6.1** Duplicate determinations should not differ from the mean by more than  $\pm 0.005$  in the range of 0.05 to 0.20 volume percent ethylene glycol monomethyl ether-glycerin.

Preparing activity.

**Air Force—WPAFB, 1964**





APPENDIX D  
DETERMINATION OF FUEL SYSTEM ICING  
INHIBITOR IN HYDROCARBON FUELS  
(Federal Test Method 5327.3)



## DETERMINATION OF FUEL SYSTEM ICING INHIBITOR IN HYDROCARBON FUELS

### 1. SCOPE

1.1 This method is used for determination of 0.05 to 0.20 volume percent ethylene glycol monomethyl ether  $\text{CH}_3\text{O}(\text{CH}_2)_2\text{OH}$  and glycerol  $\text{CHOH}(\text{CH}_2\text{OH})_2$  (synonym: methyl cellosolve and glycerin in hydrocarbon fuels). The test consists of removing the methyl cellosolve and glycerin from the hydrocarbon fuel by extraction with water. The water solution is allowed to react with an excess of standard potassium dichromate solution in the presence of sulfuric acid, and the excess dichromate is determined idometrically.

### 2. SPECIMEN

2.1 25.0 ml. of hydrocarbon fuel.

### 3. APPARATUS

3.1 Erlenmeyer flask, 50 ml.

3.2 Hotplate.

3.3 Iodine flask, 500 ml.

3.4 Separatory funnels. One hundred twenty five ml., pear shaped with supportings and stand.

3.5 Test tubes. Pyrex 22 x 175 mm., with support rack.

3.6 Volumetric glassware.

3.6.1 Burets, 25, 50 ml.

3.6.2 Pipets, 5, 10, 25 ml.

3.6.3 Flasks, 100, 500, 1000 ml.

3.7 Glass stoppered bottles.

3.8 Interval timer.

### 4. REAGENTS AND MATERIALS

Unless otherwise indicated, all reagents shall conform to the specification established by the Committee on Analytical Reagents of the American Chemical Society where such specifications are available. References to

water shall be understood to mean distilled or deionized water.

4.1 Crushed ice.

4.2 Methyl cellosolve-glycerine standard solution. Pipet 10.00 ml. of methyl cellosolve-glycerin solution into a 1-liter volumetric flask. Dilute to volume with water and mix thoroughly. Pipet 10.00 ml. of the diluted additive into 100-ml. volumetric flask, dilute to volume with water and mix thoroughly. The final solution contains 0.10 percent by volume of methyl cellosolve-glycerin.

4.3 Potassium dichromate solution, standard 0.2000 N. Dissolve exactly 4.9035 g. of potassium dichromate (dried 1 hour at 110°C.) in water. Transfer to a 500-ml. volumetric flask and dilute with water to volume. Mix thoroughly.

4.4 Potassium iodide. Crystals.

4.5 Sodium thiosulfate solution, standard 0.100 N. Dissolve  $25 \pm 0.1$  g. of sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ ) in 1 liter of water. Add 0.01 g. of sodium carbonate to stabilize the solution and mix thoroughly. Allow the solution to stand 24 hours before standardizing. This solution should be standardized every two weeks. To standardize, pipet 10.00 ml. of 0.2000 N potassium dichromate into a 500 ml. iodine flask, add 5.00 ml. of concentrated sulfuric acid slowly from a buret. Add about 50 ml. of water and cool to room temperature. Add approximately 3 g. of potassium iodide and mix thoroughly. Titrate with the sodium thiosulfate solution, swirling the liquid constantly until a brown color has changed to a yellowish green. Add 2 ml. of starch indicator solution and continue the titration until the color changes sharply from dark blue to a light bluish-green. When ap-



## METHOD 5327.3

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proaching the end point be careful to swirl the iodine flask and contents vigorously after the addition of each drop of thiosulfate. Calculate the normality of the sodium thiosulfate solution as follows:

$$\frac{\text{Normality (N) of Na}_2\text{S}_2\text{O}_3 = \frac{(\text{ml. K}_2\text{Cr}_2\text{O}_7) (\text{NK}_2\text{Cr}_2\text{O}_7)}{\text{Ml. Na}_2\text{S}_2\text{O}_3}}$$

**4.6 Starch indicator solution.** Mix 4 grams of soluble starch and 10 mg. of mercuric iodide (preservative with 10 ml. of water, and add the suspension slowly to 1 liter of boiling water). Boil for 5 minutes. Cool the solution and store in a glass stoppered bottle.

**4.7 Sulfuric acid.** Concentrated, sp. gr. 1.84.

## 5. PROCEDURE

**5.1 Determination of factor F.** Definition: factor  $F = \text{ml. of methyl cellosolve-glycerin per milli-equivalent of potassium dichromate}$ . Pipet 5.00 ml. of the methyl cellosolve-glycerin standard solution (4.2) into a 22 x 175 mm. test tube. Add from a pipet 10.0 ml. of 0.2000 *N* potassium dichromate solution and place the test tube in an ice bath. After the solution has been chilled add from a buret 5.00 ml. of concentrated sulfuric acid while constantly swirling the test tube in the ice bath. THOROUGH MIXING OF THE ACID AND AQUEOUS PHASES WITHOUT OVERHEATING IS IMPERATIVE. After the solution has cooled, place the test tube in a bath of boiling water for exactly 10 minutes. Return the test tube to the ice bath and allow to cool to room temperature or below. Transfer the contents of the test tube to a 500-ml. iodine flask. Wash the test tube 4 times with 5-ml. portions of water and add the washings to the iodine flask. Add approximately 3 g. of potassium

iodide and titrate with the standard 0.1 *N* sodium thiosulfate solution to a starch end point. The starch end point is described in 4.5. When approaching the end point be careful to swirl the iodine flask vigorously after the addition of each drop of thiosulfate.

Make three determinations of factor *F* and calculate the average value. None of the three should differ from the average by more than  $\pm 0.0001$ .

$$F = \frac{0.005}{(V_D N_D) - (V_T N_T)} = \frac{0.005}{2.00 - (V_T N_T)}$$

where:

0.005 = ml. of methyl cellosolve-glycerin in aliquot of standard solution analyzed.

$V_D$  = ml. potassium dichromate.

$N_D$  = normality of potassium dichromate.

$V_T$  = ml. sodium thiosulfate.

$N_T$  = normality of sodium thiosulfate.

**5.2 Analysis of hydrocarbon fuel.** Pipet 25.0 ml. of sample into a dry 125-ml. separatory funnel, and add from a pipet 25.0 ml. of water. Stopper the funnel and shake vigorously for 2 minutes. Allow the two phases to separate, and drain the water layer into a dry 50-ml. Erlenmeyer flask. Pipet 5.00 ml. of this solution into a 22 x 175 mm. test tube. Add from a buret or pipet 10.00 ml. of 0.2000 *N* potassium dichromate solution, and place the test tube in an ice bath. After the solution has been chilled add from a buret 5.00 ml. of concentrated sulfuric acid while constantly swirling the test tube in the ice bath. THOROUGH MIXING OF THE ACID AND AQUEOUS PHASES WITHOUT OVERHEATING IS IMPERATIVE. After the solution has cooled, place the test tube in a bath of boiling water for exactly 10 minutes. Cool the solution to room temperature in an ice bath. Quantitatively transfer the solution to a 500 ml. iodine flask, rinsing the



## METHOD 5327.3

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test tube four times with 5 ml. portions of water and adding the washings to the flask. Add approximately 3 g. of potassium iodide, and titrate with standard 0.1 N sodium thiosulfate solution to a starch end point. The starch end point is described in 4.5. When approaching the end point be careful to swirl the iodine flask vigorously after the addition of each drop of the thiosulfate. THE METHOD IS NOT APPLICABLE IF THE VOLUME OF THIOSULFATE USED IN THE TITRATION IS LESS THAN 5.0 ML.

5.3 Make a blank determination by repeating the above procedure using a sample of the fuel (under test) taken before the introduction of the additive.

## 6. CALCULATIONS

6.1 Calculate the methyl cellosolve-glycerin content of the hydrocarbon fuel as follows:

Volume % methyl cellosolve-glycerin =

$$\frac{100 F \left[ (V_D N_D) - (V_T N_T) \right]}{AS}$$

where:

F = factor defined in par. 5.1

$V_D$  = ml. of potassium dichromate.

$N_D$  = normality potassium dichromate.

$V_T$  = ml. of sodium thiosulfate.

$N_T$  = normality sodium thiosulfate.

A = aliquot fraction of water extract used.

S = ml. of hydrocarbon fuel sample.

When the instructions in this method are followed exactly, the equation may be reduced to:

Volume % methyl cellosolve-glycerine =

$$20F \left[ 2.000 - (V_T N_T) \right]$$

6.2 Calculate the value of the blank in the same manner as for the sample.

6.3 Subtract the blank value from that obtained in 6.1 to obtain the corrected volume percent of methyl cellosolve-glycerin for report. If normally high FS11 values are obtained on the finished blend at the point of receipt, it is recommended that the local Quality Control office be requested to obtain a sample of the uninhibited fuel from the source of supply to use in making blank determinations on this product.

## 7. PRECISION

Duplicate determinations should not differ from the mean by more than  $\pm 0.005$  in the range of 0.05 to 0.20 volume percent methyl cellosolve-glycerin.

Preparing activity:

Air Force--WPAFB, 1964





APPENDIX E  
THE COMPUTER PROGRAM



## THE COMPUTER PROGRAM

### Input Variables Defined

- DESAIA - the desired anti-icing content of the total cargo at equilibrium. Limited to the following values 0.10, 0.11, 0.12, 0.13, 0.14, 0.15.
- NUMWTK - the number of wing tanks the vessel has per side.
- NUMCTK - the number of center tanks in the vessel.
- PRICE - the additional cost per gallon of JP4 if the additive treatment exceeds the maximum specification limit of 0.15 per cent by volume. The additional cost is read in dollars per gallon of product.
- DRYCST - the cost per hour to operate the tanker, i.e. the dollars lost per hour while the vessel is drying tanks at the pier.
- H2OEST - the total barrels of water estimated aboard the tanker. If value is zero, the additive concentration in the fuel pumped to the ship is calculated, using the actual water aboard the vessel.
- FUELS(I) - the product quantity in barrels to be loaded into each starboard tank.
- FUELC(I) - the product quantity in barrels to be loaded into each center tank.
- FUELP(I) - the product quantity in barrels to be loaded into each port tank.



WATERS(I) - the water quantity in barrels remaining in each starboard tank.

WATERC(I) - the water quantity in barrels remaining in each center tank.

WATERP(I) - the water quantity in barrels remaining in each port tank.

Figure 12 shows the input data arrangement for a T2 class tanker.

### Symbols in the Program

COEFF - the partitioning coefficient at 80°F.

BBLINW - barrels of additive which will be absorbed by the water on board.

0.997 - volume per cent of ethylene glycol monomethyl ether in icing inhibitor.

BBLINF - barrels of additive required to satisfy the desired additive concentration in the fuel after equilibrium.

PERINJ - volume per cent of icing inhibitor to be injected into the fuel.

AFI - the initial additive quantity injected into a ship's tank which will provide icing protection.

A,B,C - the coefficients of the quadratic equation used to solve for the additive concentration in water at equilibrium.

AW - the actual barrels of additive which will be absorbed by the water in a particular ship's tank.



- AIAS TK(K) - the actual icing inhibitor concentration of the fuel in each starboard tank after equilibrium.
- AIAC TK(M) - the actual icing inhibitor concentration of the fuel in each center tank after equilibrium.
- AIAP TK(N) - the actual icing inhibitor concentration of the fuel in each port tank after equilibrium.
- TOTICE - the total barrels of icing inhibitor in all the fuel after equilibrium.
- CONCEN - the average icing inhibitor concentration of the total cargo at equilibrium.
- AICCST - the additional cost per barrel of product if additional icing inhibitor must be injected.
- AIACST - the total additional cost of the cargo due to the requirement of increasing the icing inhibitor content.
- HOURS - the point in time where drying cost equals cost to increase icing inhibitor concentration.

### Output Examples

Output data for a T2 class tanker may be found in Chapter VI. Figures 13a and 14a show output data for a vessel having a tank arrangement unlike a T2. Figures 13b and 14b show the respective economic analysis data sheets.

### The Program

The computer program follows the output examples discussed above.









# A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN J04 ABOARD A TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 257612.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 97.4
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.136 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.152 PERCENT MUST BE LOADED ABOARD THE VESSEL.

STARBOARD TANK NUMBER	FUEL QUANTITY (BARRELS)	WATER QUANTITY (BARRELS)	ICING INHIBITOR CONTENT (PERCENT BY VOLUME)
1	5002.	2.0	0.135
2	5217.	2.4	0.133
3	5632.	1.9	0.137
4	5276.	2.9	0.130
5	5124.	3.1	0.128
6	5143.	2.1	0.135
7	5633.	3.4	0.128
8	5742.	4.5	0.123
9	5214.	2.4	0.133
10	5001.	5.1	0.117

CENTER TANK NUMBER	FUEL QUANTITY (BARRELS)	WATER QUANTITY (BARRELS)	ICING INHIBITOR CONTENT (PERCENT BY VOLUME)
1	15000.	3.2	0.142
2	15321.	5.1	0.137
3	14990.	4.3	0.139
4	15218.	2.1	0.145
5	15421.	4.6	0.139
6	15204.	3.1	0.142
7	14936.	2.0	0.145
8	15231.	5.1	0.137
9	15000.	3.2	0.142
10	15321.	5.1	0.137

PORT TANK NUMBER	FUEL QUANTITY (BARRELS)	WATER QUANTITY (BARRELS)	ICING INHIBITOR CONTENT (PERCENT BY VOLUME)
1	5002.	2.0	0.135
2	5217.	2.4	0.133
3	5632.	1.9	0.137
4	5276.	2.9	0.130
5	5124.	3.1	0.128
6	5143.	2.1	0.135
7	5633.	3.4	0.128
8	5742.	4.5	0.123
9	5214.	2.4	0.133
10	5001.	5.1	0.117

Figure 13a - Simulation Output Data for a Tanker Other Than a T2



ECONOMIC ANALYSIS  
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COST TO INCREASE ICING INHIBITOR CONCENTRATION OF THIS CARGO ABOVE 0.15 PERCENT = \$ 4327.88  
COST TO DRY SHIP = \$ 196.00 PER HOUR.

IF DRYING TIME IS 4 HOURS, AN ADDITIONAL COST OF \$ 3544. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.  
IF DRYING TIME IS 8 HOURS, AN ADDITIONAL COST OF \$ 2760. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.  
IF DRYING TIME IS 12 HOURS, AN ADDITIONAL COST OF \$ 1976. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.  
IF DRYING TIME IS 16 HOURS, AN ADDITIONAL COST OF \$ 1192. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.  
IF DRYING TIME IS 24 HOURS, \$ 376. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.  
IF DRYING TIME IS 36 HOURS, \$ 2728. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.  
IF DRYING TIME IS 48 HOURS, \$ 5080. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.  
IF DRYING TIME IS 60 HOURS, \$ 7432. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.  
IF DRYING TIME IS 72 HOURS, \$ 9784. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.

IF DRYING TIME IS GREATER THAN 22.1 HOURS, IT WILL BE MORE ECONOMICAL TO ADD ADDITIONAL ICING INHIBITOR.

Figure 13b - Economic Analysis



# A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 257612.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 97.4
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.128 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.143 PERCENT MUST BE LOADED ABOARD THE VESSEL.

WATER ESTIMATE WAS 22.0 BARRELS.

STARBOARD TANK NUMBER	FUEL QUANTITY (BARRELS)	WATER QUANTITY (BARRELS)	ICING INHIBITOR CONTENT (PERCENT BY VOLUME)
1	5002.	2.0	0.127
2	5217.	2.4	0.125
3	5632.	1.9	0.129
4	5276.	2.9	0.122
5	5124.	3.1	0.121
6	5143.	2.1	0.127
7	5633.	3.4	0.121
8	5742.	4.5	0.116
9	5214.	2.4	0.125
10	5001.	5.1	0.110

CENTER TANK NUMBER	FUEL QUANTITY (BARRELS)	WATER QUANTITY (BARRELS)	ICING INHIBITOR CONTENT (PERCENT BY VOLUME)
1	15000.	3.2	0.134
2	15321.	5.1	0.129
3	14980.	4.3	0.131
4	15218.	2.1	0.137
5	15421.	4.6	0.131
6	15206.	3.1	0.134
7	14934.	2.0	0.137
8	15211.	5.1	0.129
9	15000.	3.2	0.134
10	15321.	5.1	0.129

PORT TANK NUMBER	FUEL QUANTITY (BARRELS)	WATER QUANTITY (BARRELS)	ICING INHIBITOR CONTENT (PERCENT BY VOLUME)
1	5002.	2.0	0.127
2	5217.	2.4	0.125
3	5632.	1.9	0.129
4	5276.	2.9	0.122
5	5124.	3.1	0.121
6	5143.	2.1	0.127
7	5633.	3.4	0.121
8	5742.	4.5	0.116
9	5214.	2.4	0.125
10	5001.	5.1	0.110

Figure 14a - Simulation Output Data for a Tanker Other Than a T2





ECONOMIC ANALYSIS  
-----

COST TO DRY SHIP = \$ 196.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.143. SINCE THIS CONCENTRATION IS NOT ABOVE THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.128 PERCENT. NO TANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE SAVED.

IF DRYING TIME IS 4 HOURS, \$	784.	WILL BE SAVED.
IF DRYING TIME IS 8 HOURS, \$	1568.	WILL BE SAVED.
IF DRYING TIME IS 12 HOURS, \$	2352.	WILL BE SAVED.
IF DRYING TIME IS 16 HOURS, \$	3136.	WILL BE SAVED.
IF DRYING TIME IS 24 HOURS, \$	4704.	WILL BE SAVED.
IF DRYING TIME IS 36 HOURS, \$	7056.	WILL BE SAVED.
IF DRYING TIME IS 48 HOURS, \$	9408.	WILL BE SAVED.
IF DRYING TIME IS 60 HOURS, \$	11760.	WILL BE SAVED.
IF DRYING TIME IS 72 HOURS, \$	14112.	WILL BE SAVED.

Figure 14b - Economic Analysis



## AN ICING INHIBITOR EQUILIBRIUM SIMULATION

C	AN ICING INHIBITOR EQUILIBRIUM SIMULATION	C
C	.....	C
C		C
C		C
C	A SIMULATION OF ICING INHIBITOR EQUILIBRIUM CONDITIONS ABOARD A TANKER	C
C	.....	C
C		C
C	DIMENSION FUELS(15),FUELCO(15),FUELPL(15),WATERS(15),WATERC(15),WATE	
	1RP(15),AIASHT(15),AIACHT(15),AIAPHT(15),TKCOST(100),ALOSS(100),GAI	
	2A(100)	
	COEFF=220.	
CC	READ IN DESIRED ICING INHIBITOR CONTENT OF TOTAL CARGO(IN PERCENT),NUMBER	
CC	OF WING TANKS VESSEL HAS DIVIDED BY 2,NUMBER OF CENTER TANKS VESSEL HAS,	
CC	ADDITIONAL COST PER GALLON OF PRODUCT IF ICING INHIBITOR TREATMENT EXCEEDS	
CC	MAXIMUM SPECIFICATION LIMIT OF 0.15 PERCENT (COST IS READ IN \$), COST	
CC	PER HOUR TO OPERATE TANKER(X),ESTIMATED BARRELS OF WATER REMAINING ABOARD	
CC	TANKER(OPTIONAL)	
	1 READ(5,201)DESAIA,NUMWTK,NUMCTK,PRICE,DRYCST,H2OEST	2
201	FORMAT(F10.3,2I10,F10.5,2F10.2)	7
	IF(DESAIA.EQ.0.0)GO TO 999	7
CC	READ IN FUEL QUANTITIES FROM BOW TO STERN FOR EACH CARGO TANK IN	
CC	FOLLOWING ORDER - ALL STARBOARD TANKS, ALL CENTER, ALL PORT TANKS	
	READ(5,202)(FUELS(I),I=1,NUMWTK)	10
	READ(5,202)(FUELCO(I),I=1,NUMCTK)	15
	READ(5,202)(FUELPL(I),I=1,NUMWTK)	20
202	FORMAT(8F10.0)	25
CC	READ IN ACTUAL WATER QUANTITIES IN SAME ORDER AS FUEL	
	READ(5,203)(WATERS(I),I=1,NUMWTK)	25
	READ(5,203)(WATERC(I),I=1,NUMCTK)	30
	READ(5,203)(WATERP(I),I=1,NUMWTK)	35
203	FORMAT(8F10.1)	40
CC	DESIRED AVERAGE ICING INHIBITOR SETS ESTIMATED PERCENTAGE OF ADDITIVE	
CC	TO BE ABSORBED BY WATER	
	IF(DESAIA.EQ.0.15)AHSPPR=0.335	40
	IF(DESAIA.EQ.0.14)AHSPPR=0.310	43
	IF(DESAIA.EQ.0.13)AHSPPR=0.295	46
	IF(DESAIA.EQ.0.12)AHSPPR=0.265	49
	IF(DESAIA.EQ.0.11)AHSPPR=0.245	52
	IF(DESAIA.EQ.0.10)AHSPPR=0.220	55
CC	WATER AND FUEL QUANTITIES ARE SUMMED UP	
	WATER1=0.0	58
	WATER2=0.0	59
	WATER3=0.0	60
	SUM1=0.0	61
	SUM2=0.0	62
	SUM3=0.0	63
	DO 2A=1,NUMWTK	64
	SUM2=FUELS(N)+SUM2	65



## AN ICING INHIBITOR EQUILIBRIUM SIMULATION

	WATER2=WATERS(N)+WATER2	66
	SUM1=FUEL(N)+SUM1	67
	WATER1=WATER(N)+WATER1	68
2	CONTINUE	69
	DO 3J=1,NUMCTK	71
	SUM3=FUEL(J)+SUM3	72
	WATER3=WATER(J)+WATER3	73
3	CONTINUE	74
	FUEL=SUM1+SUM2+SUM3	76
	TOTH2O=WATER1+WATER2+WATER3	77
CC	IF NO WATER ESTIMATE IS PROVIDED, THE ADDITIONAL BARRELS OF ADDITIVE	
CC	REQUIRED ARE CALCULATED USING THE ACTUAL WATER QUANTITY	
	IF (H2OEST.FO.0.0) GO TO 4	78
CC	IF A WATER ESTIMATE IS PROVIDED, THE ADDITIONAL BARRELS OF ADDITIVE	
CC	REQUIRED ARE CALCULATED USING THE ESTIMATED WATER QUANTITY	
	RBLINW=AHSPER*H2OEST/0.997	81
	GO TO 5	82
4	RBLINW=AHSPER*TOTH2O/0.997	83
CC	BARRELS OF ADDITIVE TO SATISFY DESIRED INHIBITOR CONTENT OF FUEL ARE	
CC	DETERMINED	
5	RBLINF=(DESAIA/100.+(FUEL-RBLINW))/0.997	84
CC	TOTAL BARRELS OF ICING INHIBITOR TO BE ADDED TO CARGO ARE DETERMINED	
	TOTALA=RBLINF+RBLINW	85
	ALAINJ=TOTALA/FUEL	86
	PEFINJ=ALAINJ*100.	87
CC	ICING INHIBITOR CONCENTRATION OF STARBOARD TANKS ARE DETERMINED AFTER	
CC	EQUILIBRIUM HAS BEEN ESTABLISHED	
	DO 6 K=1,NUMCTK	88
	IF (FLELS(K).FO.0.0) GO TO 7	89
	AFI=FUELS(K)*ALAINJ*0.997	92
	A=COEFF/FUELS(K)	93
	B=(A*WATERS(K))-(A*AFI)+1.0	94
	C=-A*WATERS(K)*AFI	95
	AW=(-B+SQRT((B**2.)-(4.*A*C)))/(2.*A)	96
	AJASTK(K)=((AFI-AW)*100.)/FUELS(K)	97
	GO TO 6	98
7	AJASTK(K)=0.0	99
6	CONTINUE	100
CC	ICING INHIBITOR CONCENTRATION OF CENTER TANKS ARE DETERMINED AFTER	
CC	EQUILIBRIUM HAS BEEN ESTABLISHED	
	DO 8 M=1,NUMCTK	102
	IF (FUELC(M).FO.0.0) GO TO 9	103
	AFI=FUELC(M)*ALAINJ*0.997	106
	A=COEFF/FUELC(M)	107
	B=(A*WATERC(M))-(A*AFI)+1.0	108
	C=-A*WATERC(M)*AFI	109
	AW=(-B+SQRT((B**2.)-(4.*A*C)))/(2.*A)	110
	AJACTK(M)=((AFI-AW)*100.)/FUELC(M)	111
	GO TO 8	112
9	AJACTK(M)=0.0	113



## AN ICING INHIBITOR EQUILIBRIUM SIMULATION000000

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      8 CONTINUE
CC      ICING INHIBITOR CONCENTRATION OF PORT TANKS ARE DETERMINED AFTER
CC      EQUILIBRIUM HAS BEEN ESTABLISHED
      DO 10N=1,NUMWTX
      IF(FUELP(N),F0,0.0)GO TO 11
      AFI=FUELP(N)*ATAINJ*0.997
      AECOEFF=FUELP(N)
      B=(A*WATERP(N))-(A*AFI)+1.0
      C=A*WATERP(N)*AFI
      AW=(-B+SQRT((B**2.)-(4.*A*C)))/(2.*A)
      AIAPT(K(N))=((AFI-AW)*100.)/FUELP(N)
      GO TO 10
11      AIAPT(K(N))=0.0
10 CONTINUE
CC      THE BARRELS OF ICING INHIBITOR IN THE FUEL IN EACH TANK IS DETERMINED
CC      AND THEY ARE SUMMED,
      BLICES=0.0
      BLICEP=0.0
      BLICEC=0.0
      DO 12 I=1,NUMWTX
      BLICES=((AIAPT(I)*FUELS(I))/100.)*BLICES
      BLICEP=((AIAPT(I)*FUELP(I))/100.)*BLICEP
12 CONTINUE
      DO 13 J=1,NUMCTK
      BLICEC=((AIAPT(J)*FUELC(J))/100.)*BLICEC
13 CONTINUE
      TOTICE=BLICEC+BLICEP+BLICES
CC      THE ACTUAL ICING INHIBITOR CONCENTRATION OF THE TOTAL CARGO IS DETERMINED
      CONGEN=(TOTICE/FUEL)*100.
CC      IF THE VESSEL HAS MORE THAN 8 CENTER TANKS IT IS NOT A T-2 AND TABULAR
CC      RESULTS ARE WRITTEN OUT, IF THE SHIP HAS 8 CENTER TANKS, IT IS ASSUMED
CC      THE TANK LAYOUT IS THE SAME AS THAT OF A T-2, A DIAGRAM IS PRODUCED AND
CC      THE RESULTS ARE NOTED ON THE DIAGRAM,
      IF(NLMCTK,F0,B)GO TO 14
      GO TO 15
14      WRITE(6,100)
100      FORMAT(1H1)
      WRITE(6,101)DESATA,FUEL,TOTICE,CONGEN,PERINJ
101      FORMAT(29X,73HA SIMULATION OF ICING INHIBITOR CONCENTRATIONS I
1N 3P4 ABOARD A T-2 TANKER,/,30X,73H-----,/,36X,48H1, DESIRED AN
2-----,/,33X,65H2, MIL
3TI-ICING CONTENT OF TOTAL CARGO =,F6,3.9H PERCENT,/,33X,65H2, MIL
4ITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME,/,44X,
536F3, TOTAL BARRELS OF PRODUCT LOADED =,F8,0,/,18X,
5          90H4, TOTAL BARRELS
6 OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS PO
7SSIBLE =,F6,1,/,12X,102H5, IN ORDER TO COMBAT THE WATER ABOARD AND
8 STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF,F6,3.
9/,13X,57H PERCENT,PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF
1,F6,3,42H PERCENT MUST BE LOADED ABOARD THE VESSEL,/,31X70HTHE D

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## AN ICING INHIBITOR EQUILIBRIUM SIMULATION000000

2. DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK,  
3/, 31X, 71H (BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF IC  
4. INE INH, RITOR), 77, 25X, 1H2, 12X, 1H3, 12X, 1H4, 12X, 1H5, 12X, 1H6, 12X, 1H7,  
512X, 1H8, 1H9, 1H9)

```
WRITE(6,102)FUELS(2),FUELS(3),FUFLS(4),FUELS(5),FUELS(6),FUELS(7),
1FUELS(8),FUELS(9)
```

Y02 FORMAT(19X,I05H-----)

[illegible]

```
103 FORMAT(7X,1H*,2X,F7.1,2X,1H
```

```

1HI,12X,1HI,12X,1HI,12X,1HI,/,5X,1H*,13X,1HI,12X,1HI,12X,1HI,12X,1H
2I,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,3X,1H*,15X,1HI,12X,1HI,1
3,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,1X,1H*
41H-----,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X
5HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X
6,F7,1,3X,1HI,6HCENTER,/,3X,1H*,15X,1HI,12X,1HI,12X,1HI,12X,1HI,12X
7,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,5X,1H*,13X,1HI,12X,1HI,12X,
8HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,7X,1H*,2X,F7
9,1,2X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,
112X,1HI,/,9X,1H*,9X,1HI,12H-----,1HI,12H-----,1HI,1
12H-----,1HI,12H-----,1HI,12H-----,1HI,12H-----,1HI,12H-----
2-----,1HI,12H-----,1HI,12H-----,1HI,/,11X,1H*,7X,
3HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1H
4I,/,13X,1H*,5X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI
5,12X,1HI,12X,1HI,/,15X,1H*,7X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X
6,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,
73X,1HI,2X,F7,1,3X,1HI,4HPORT,/,17X,1H*,1X,1HI,12X,1HI,12X,1HI,12X,
8HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1H
WRITE(6,104)

```

```
104 FORMAT(19X,105H-----)
```

2 THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK  
3K AND THE ,/24X, 24H RESULTING ICING INHIBITOR CONCENTRATION IN PERC  
4 ENT BY VOLUME AFTER WATER EXTRACTION.)

```
IF (H2OEST.EQ.0.0) GO TO 16
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WRITE(6,105)H2OEST
```

3-FORMAT(30X,18H) WATER-ESTIMATE



## AN ICING INHIBITOR EQUILIBRIUM SIMULATION0000000

106	FORMAT(/,25X,1H2,12X,1H3,12X,1H4,12X,1H5,12X,1H6,12X,1H7,12X,1H8, 112X,1H9)	169
	WRITE(A,107)WATERS(2),WATERS(3),WATERS(4),WATERS(5),WATERS(6),WATE 1RS(7),WATERS(8),WATERS(9),AIASTK(2),AIASTK(3),AIASTK(4),AIASTK(5), 2AIASTK(6),AIASTK(7),AIASTK(8),AIASTK(9),WATERS(1),AIASTK(1),WATERC 3(1),WATERC(2),WATERC(3),WATERC(4),WATERC(5),WATERC(6),WATERC(7),WA 4TERC(8)	169
107	FORMAT(19X,105H-----)	172
	1-----,17X1H*,1X 2,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1 3H1,/,15X,1H*,3X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3 4X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1 5,4X,1H1,4HSTRT,/,13X,1H*,5X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F 66,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X 7,1H1,3X,F6,3,3X,1H1,/,8X,2H1,1X,1H*,7X,1H1,12X,1H1,12X,1H1,12X,1H 81,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,/,9X,1H*,9X,1H1,12H----- 9-----,1H1,12H-----,1H1,12H-----,1H1,12H----- 1-----,1H1,12H-----,1H1,12H-----,1H1,12H-----,1H1, 212H-----,1H1,/,7X,1H*,2X,F5,1,4X,1H1,12X,1H1,12X,1H1,12X,1H 31,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,/,5X,1H*,4X,F6,3,3X,1H1, 412X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,/ 53X,1H*,15X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X 6,1H1,12X,1H1,/,1X,1H*,17H-----,1H1,3X,F5,1,4X,1H1,3X,F 75,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X 8,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,6HCENTER)	
	WRITE(A,108)AIACTK(1),AIACTK(2),AIACTK(3),AIACTK(4),AIACTK(5),AIACT 1TK(6),AIACTK(7),AIACTK(8),WATERP(1),AIAPTK(1),WATERP(2),WATERP(3), 2WATERP(4),WATERP(5),WATERP(6),WATERP(7),WATERP(8),WATERP(9),AIAPTK 3(2),AIAPTK(3),AIAPTK(4),AIAPTK(5),AIAPTK(6),AIAPTK(7),AIAPTK(8),AI 4APTK(9)	172
108	FORMAT(3X,1H*,15X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1 1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6 2,3,3X,1H1,/,5X,1H*,4X,F5,1,4X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1, 312X,1H1,12X,1H1,12X,1H1,12X,1H1,/,7X,1H*,2X,F6,3,3X,1H1,12X,1H1,12 4X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,/,9X,1H*,9X, 51H1,12H-----,1H1,12H-----,1H1,12H-----,1H1,12H-----,1H1,12 6H-----,1H1,12H-----,1H1,12H-----,1H1,12H-----,1H1,12H----- 7-----,1H1,12H-----,1H1,/,11X,1H*,7X,1H1,12X,1H1,12X,1H1,1 82X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,/,13X,1H*,5X,1H1,3X 9,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1, 14X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,3X,F5,1,4X,1H1,/,15X,1H*,3X,1 2H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X, 7F6,3, 33X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,3X,F6,3,3X,1H1,4HPORT,/,1 47X,1H*,1X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X,1H1,12X, 51H1,12X,1H1,/,19X,105H----- 6----- GO TO 17	175
15	WRITE(6,109)	176
109	FORMAT(1H1)	178



## AN ICING INHIBITOR EQUILIBRIUM SIMULATION000000

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WRITE(6,110)DESAT,FUEL,TOTW20,CONCN,PERINJ
110 FORMAT(//,29X,69HA SIMULATION OF ICING INHIBITOR CONCENTRATIONS I
1A SP4 ABOARD A TANKER,/,30X,69H
2-----,/,36X,46H1, DESIRED ANTI-ICING
3 CONTENT OF TOTAL CARGO =,F6.3,9H PERCENT,/,33X,65H2, MILITARY SP
4 ECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME,/,44X,36H3, TO
5 TAL BARRELS OF PRODUCT LOADED =,F8.0,/,18X,90H4, TOTAL BARRELS OF
6 WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIB
7 LE =,F6.1,/,12X,102H5, IN ORDER TO COMBAT THE WATER ABOARD AND STI
8 LL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF, F6.3,/,13
9 X,57H PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF, F6.
13,42H PERCENT MUST BE LOADED ABOARD THE VESSEL.)
IF(CH2OFST.F0,0.0)GO TO 28
WRITE(6,127)H2OEST
127 FORMAT(50X,18HWATER ESTIMATE WAS, F6.1,9H BARRELS.)
28 WRITE(6,128)
128 FORMAT(//,32X,9HSTARBOARD, 4X,13HFUEL QUANTITY,3X,14HWATER QUANTIT
1Y,3X,23HICING INHIBITOR CONTENT,/,31X,11HTANK NUMBER,5X,9H(BARR
2ELS),7X,9H(BARRELS),8X,19H(PERCENT BY VOLUME),/,31X,11H-----,5X,
39H-----,7X,9H-----,8X,19H-----,/)
DO 18 I=1,NUMMTK
18 WRITE(6,111)I,FUELS(I),WATERS(I),AIASLK(I)
111 FORMAT(34X,13,10X,F8.0,10X,F5.1,16X,F6.3)
WRITE(6,112)
112 FORMAT(///,33X,6HCENTER,5X,13HFUEL QUANTITY,3X,14HWATER QUAN
1TITY,3X,23HICING INHIBITOR CONTENT,/,31X,11HTANK NUMBER,5X,9H(BARR
2ELS),7X,9H(BARRELS),8X,19H(PERCENT BY VOLUME),/,31X,11H-----,
3,5X,9H-----,7X,9H-----,8X,19H-----,/)
DO 19 K=1,NUMCTK
19 WRITE(6,113)K,FUELC(K),WATERC(K),AIACLK(K)
113 FORMAT(34X,13,10X,F8.0,10X,F5.1,16X,F6.3)
WRITE(6,114)
114 FORMAT(///,34X,4HPORT,7X,13HFUEL QUANTITY,3X,14HWATER QUANTIT
1Y,3X,23HICING INHIBITOR CONTENT,/,31X,11HTANK NUMBER,5X,9H(BARR
2),7X,9H(BARRELS),8X,19H(PERCENT BY VOLUME),/,31X,11H-----,5X,
39H-----,7X,9H-----,8X,19H-----,/)
DO 20 J=1,NUMHTK
20 WRITE(6,115)J,FUELP(J),WATERP(J),AIAPTK(J)
115 FORMAT(34X,13,10X,F8.0,10X,F5.1,16X,F6.3)
17 WRITE(6,116)
116 FORMAT(1H17 //,57X,17HECONOMIC ANALYSIS,/,
157X,17H-----,/)
CC IF THE FUEL PUMPED TO THE SHIP HAS AN ICING INHIBITOR CONCENTRATION
CC GREATER THAN 0.150 PERCENT, AN ADDITIONAL COST IS CHARGED FOR THE EXTRA
CC INHIBITOR.
IF(PERINJ.LE.0.15)GO TO 25
AICOST=42.*PRICE
CC THE TOTAL COST OF THE ADDITIONAL ICING INHIBITOR IS DETERMINED.
AIACST=AICOST*FUEL
CC THE POINT AT WHICH DRYING COST EQUALS ADDITIONAL ICING INHIBITOR COST

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## AN ICING INHIBITOR EQUILIBRIUM SIMULATION000000

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CC  IS DETERMINED.
      HOLRS=A1ACST/DRYCST
      WRITE(A,117)DRYCST,A1ACST
117  FORMAT(48X,20HCOST TO DRY SHIP = $,F7.2,10H PER HOUR,,,20X,A3HCOS
      IT TO INCREASE ICING INHIBITOR CONCENTRATION OF THIS CARGO ABOVE 0.
      215 PERCENT = $,F8.2,/)
CC  VARIOUS DRYING TIMES ARE ASSUMED AND THE COST (OR SAVINGS) RESULTING
CC  FROM INJECTING ADDITIONAL ICING INHIBITOR IS DETERMINED.
      DO 21 I=4,16,4
      HOLRR=I
      TKCOST(I)=HOLRR*DRYCST
      IF(TKCOST(I).GT.A1ACST)GO TO 22
      ALCSS(I)=A1ACST-TKCOST(I)
      WRITE(A,118)I,ALCSS(I)
118  FORMAT(2X,17HIF DRYING TIME IS,13,30H HOURS,AN ADDITIONAL COST OF
      1$,F7.0,72H WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONT
      2ENT OF THE FUEL,/)
      GO TO 21
22  GAIN(I)=TKCOST(I)-A1ACST
      WRITE(A,119)I,GAIN(I)
119  FORMAT(6X,17HIF DRYING TIME IS,13,30H HOURS,$,F7.0,87H WILL BE SAVE
      1D BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYIN
      2G TANKS,)
21  CONTINUE
      DO 23 N=24,72,12
      HOLRR=N
      TKCOST(N)=HOLRR*DRYCST
      IF(TKCOST(N).GT.A1ACST)GO TO 24
      ALCSS(N)=A1ACST-TKCOST(N)
      WRITE(A,120)N,ALCSS(N)
120  FORMAT(2X,17HIF DRYING TIME IS,13,30H HOURS,AN ADDITIONAL COST OF
      1$,F7.0,72H WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONT
      2ENT OF THE FUEL,/)
      GO TO 23
24  GAIN(N)=TKCOST(N)-A1ACST
      WRITE(A,121)N,GAIN(N)
121  FORMAT(6X,17HIF DRYING TIME IS,13,30H HOURS,$,F7.0,87H WILL BE SAVE
      1D BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYIN
      2G TANKS,)
23  CONTINUE
      WRITE(A,122)HOURS
122  FORMAT(///,14X,30HIF DRYING TIME IS GREATER THAN,F6.1,48H HOURS,IT
      1 WILL BE MORE ECONOMICAL TO ADD ADDITIONAL ICING INHIBITOR,)
      GO TO 1
CC  IF THE FUEL PUMPED TO THE VESSEL HAS AN ICING INHIBITOR CONCENTRATION NOT
CC  EXCEEDING 0.150 PERCENT, THERE ARE NO ADDITIONAL ANTI-ICING COSTS
25  WRITE(6,123)DRYCST
123  FORMAT(48X,20HCOST TO DRY SHIP = $,F7.2,10H PER HOUR,/)
      WRITE(6,124)PERINJ,CONCN
124  FORMAT(
      3X,30HTHIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN I

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## AN ICING INHIBITOR EQUILIBRIUM SIMULATION0000000

1 ICING INHIBITOR CONCENTRATION OF .F6.3.32H. SINCE THIS CONCENTRATION  
 2 IS NOT ABOVE .7.3X.126H THE MAXIMUM MILITARY SPECIFICATION LIMIT OF  
 3 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INH  
 4 IBITOR. THE FINAL .7.3X.43H TOTAL CARGO INHIBITOR CONCENTRATION WILL  
 5 BE .F6.3.76H PERCENT. NO TANK DRYING IS REQUIRED AND THEREFORE ALL  
 7 DRYING TIME COSTS ARE .7.3X.6HSAVED. (//)

CC COSTS WHICH WILL BE SAVED BY NOT DRYING ARE DETERMINED BY ASSUMING VARIOUS  
 CC DRYING TIMES.

DO 25 K=4.16.4

HOLRR=M

TKCOST(K)=HOLRR\*DRYCST

WRITE(6,125)K,TKCOST(K)

125 FORMAT(41X,17HIF DRYING TIME IS .13.8H HOURS, \$.F7.0.15H WILL BE SAV  
 1ED:)

26 CONTINUE

DO 27 M=24.72.12

HOLRR=M

TKCOST(M)=HOLRR\*DRYCST

WRITE(6,126)M,TKCOST(M)

126 FORMAT(41X,17HIF DRYING TIME IS .13.8H HOURS, \$.F7.0.15H WILL BE SAV  
 1ED:)

27 CONTINUE

GO TO 1

999 STOP

END

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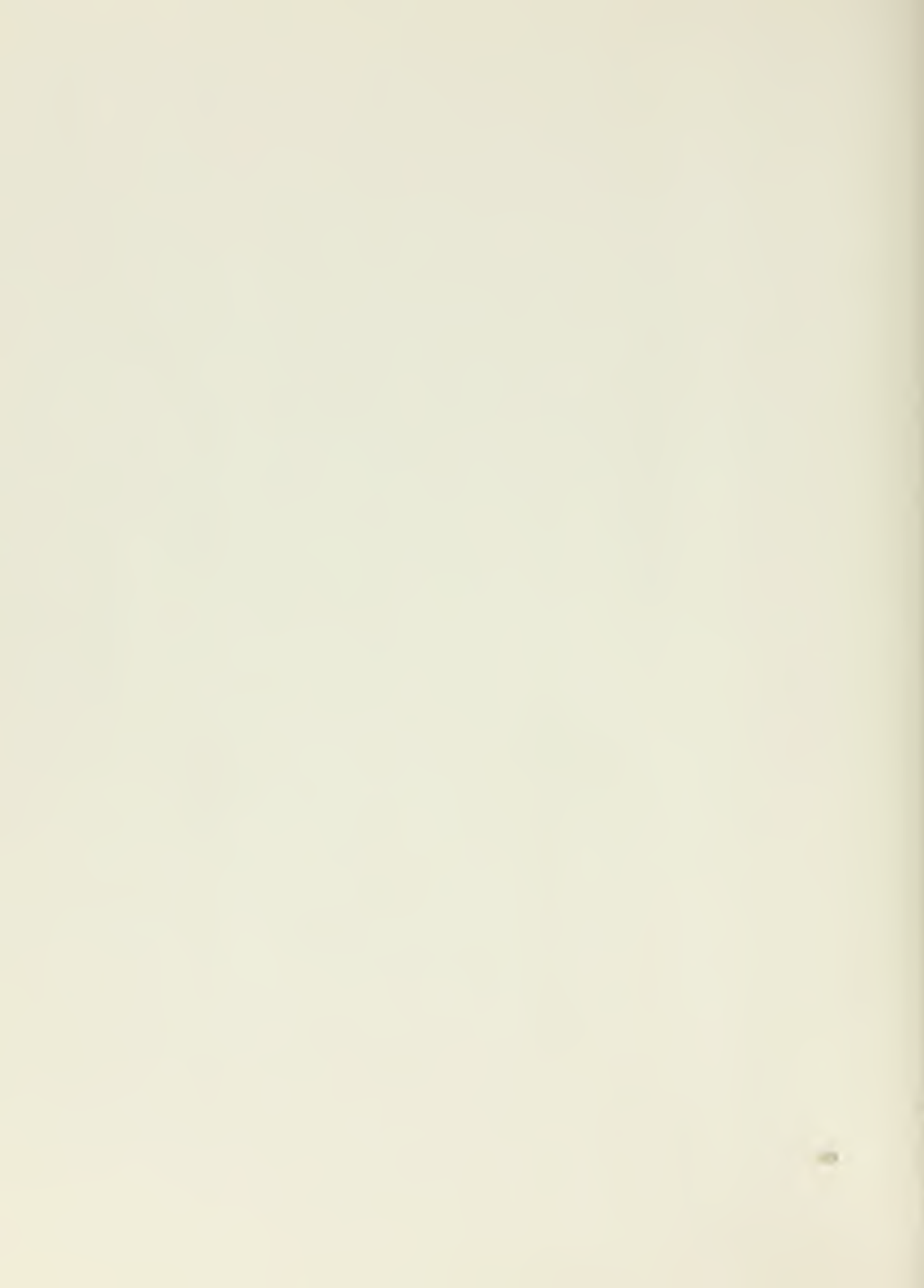
















thesM337

The development of a method to load JP4



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